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TRW Environmental Engineering Div, Redondo Beach, CA

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Mar 79

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Environmental Protection
Agency

Industrial Environmental Research
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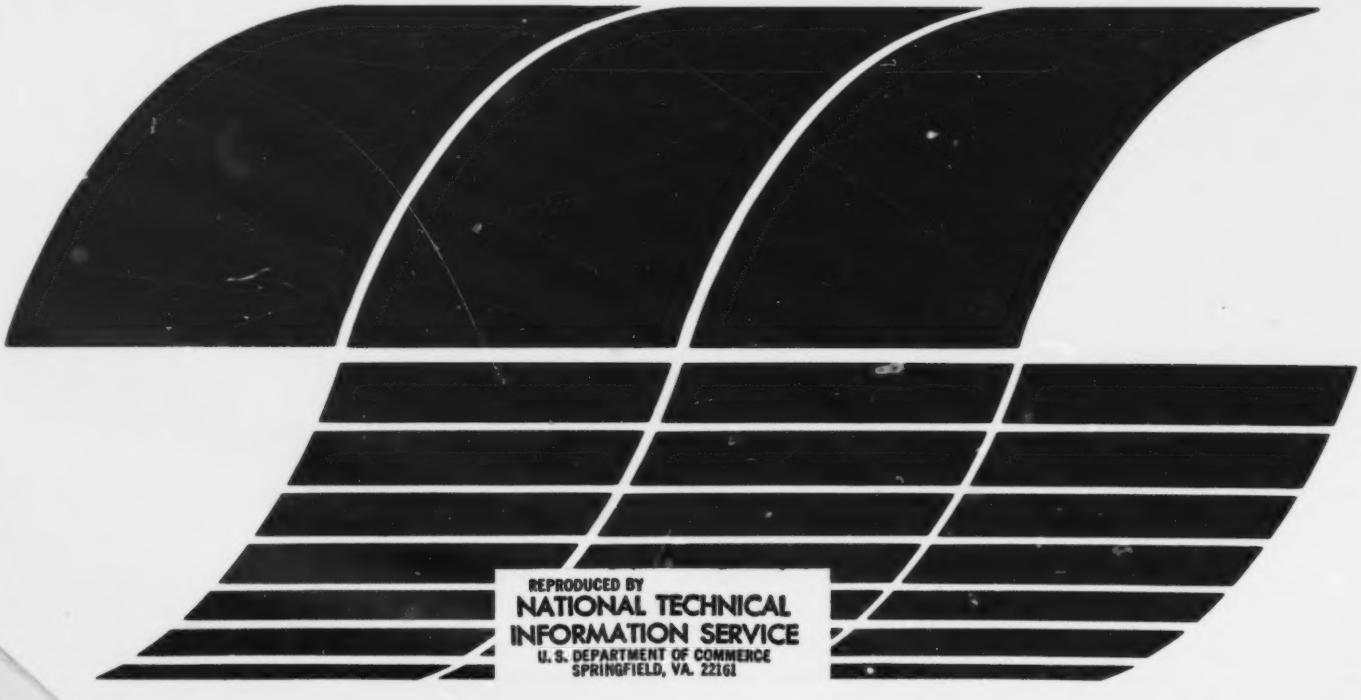
Technological Overview Reports for Eight Shale Oil Recovery Processes

Interagency Energy/Environment R&D Program Report



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16. ABSTRACT

This report has been prepared to assist research workers by providing up-to-date descriptions of processes at the forefront of oil shale development. The purpose of the document is to supply background information for evaluation of environmental impacts and pollution control technologies in connection with oil shale development. All of the reported shale oil processes have been tested on a sufficient pilot scale (0.1-0.5 m^3/day oil production) to permit an evaluation of their operating characteristics and yields. Six surface retorting processes selected for characterization were: (1) Union Oil Retort B, (2) Paraho, (3) TOSCO II, (4) Lurgi Ruhrgas, (5) Superior Oil, and (6) USBM Gas Combustion. In addition, two in-situ retorting activities were selected: (1) the Occidental modified in-situ retort, and (2) the true in-situ development programs of Laramie Energy Technology Center (DOE).

Each overview report contains available information on oil shale processing. General process descriptions, shale preparation requirements, equipment types, operating conditions, process products and by-products, physical and chemical characteristics, energy and water requirements, process stream characteristics, processed shale disposal requirements, and site-specific environmental aspects are included.

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TECHNOLOGICAL OVERVIEW REPORTS FOR EIGHT SHALE OIL RECOVERY PROCESSES

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INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

An analysis of environmental impacts begins with describing potential pollutant sources for a variety of physical settings. For shale oil development, this effort has resulted in up-to-date descriptions of the leading shale processing technologies, which are compiled and presented in this document. It is anticipated that some of these processes will be used to provide shale oil for energy or petrochemical needs in the not-too-distant future. The overviews can serve users as a solid basis for additional studies or as information sources leading to an awareness of what is involved in shale oil processing. Further information on the environmental aspects of shale oil processing can be obtained from the IERL-Cincinnati Fuels Technology Branch.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

This report, "Technological Overview Reports for Eight Oil Shale Recovery Processes," has been prepared to assist research workers by providing up-to-date descriptions of processes at the forefront of shale oil development. The purpose of the document is to supply background information to aid in the evaluation of environmental impacts and pollution control technologies in connection with oil shale development. In order to be included in the report, processes for shale oil production had to be able to meet certain criteria indicating commercial promise. All of the reported processes have been tested on a sufficient pilot scale (0.1-0.5 m^3/day oil production) to permit an evaluation of their operating characteristics and yields. Six surface retorting processes were selected for characterization: (1) Union Oil Retort B, (2) Paraho, (3) TOSCO II, (4) Lurgi Ruhrgas, (5) Superior Oil, and (6) USBM Gas Combustion. In addition, two in-situ retorting processes were selected: the Occidental modified in-situ retort, and the true in-situ development programs of Laramie Energy Technology Center (Department of Energy, DOE).

Each of the overview reports contains information on general process description, shale preparation requirements, equipment types, operating conditions (e.g., temperature, feed rate), physical and chemical characteristics of process products and by-products, energy and water requirements, process stream characteristics, retorted shale disposal requirements, and site-specific aspects.

This report was submitted in partial fulfillment of Contract 68-02-1881 by TRW Environmental Engineering Division under the sponsorship of the U.S. Environmental Protection Agency. Work was subcontracted to Denver Research Institute.

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INTRODUCTION

The work plan for the EPA project "Assessment of Environmental Impacts from Oil Shale Developments" identifies characterization of leading recovery processes as a key element. An analysis of effluent and emission impacts necessarily begins with the pollutant sources, as well as the variety of physical settings where shale oil recovery plants might be constructed. Accordingly, a number of technology overview reports have been prepared by the staff of TRW and Denver Research Institute, in order to assist in the evaluation of environmental impacts and pollution control technologies.

Since these overviews provide basic and up-to-date descriptions of processes at the forefront of shale oil development, this information is compiled and presented in this publication. This document will serve as input to the final assessment report and, hopefully, will prove to be useful as an individual reference.

Although several hundred different processes for retorting oil shale have been proposed over the past 75 years, only a few have been sufficiently investigated to be considered viable for commercial development. In order to be included in the current EPA evaluation it was felt that any present-day process for shale oil production should be able to meet a majority of the following criteria:

(a) The process has been tested on a sufficient pilot scale (0.1-0.5 m^3/day or 0.6-3 bbls/day oil production) to permit an evaluation of its operating characteristics and yields.

(b) The data obtained to date have indicated that the process is technically sound and is amenable to further scale-up to a large pilot plant, semi-works plant, or single commercial module.

(c) Process operation up to the present time has not indicated any inherent adverse environmental emissions or effluents which are considered to be incapable of eventual control.

(d) The process has operated successfully on United States oil shales, particularly those of the Western Green River Formation.

(e) The preliminary economics of the process are sufficiently promising for the future to warrant continued process development.

(f) There are some indications that construction of a commercial module (1000 m^3/stream day or 6000 bbls/day) will be in progress before 1985.

(g) Some reasonable measure of cooperation could be secured from a process developer in obtaining unpublished information, descriptions of new process changes, etc.

Six surface retorting processes were selected for characterization on the basis of the above criteria: (1) Union Oil Retort B, (2) Paraho, (3) TOSCO II, (4) Lurgi-Ruhrgas, (5) Superior Oil, and (6) USBM Gas Combustion. In addition, two in-situ retorting processes were selected: (1) the Occidental modified in-situ retort, and (2) true in-situ development programs of Laramie Energy Technology Center (DOE).

In true in-situ processes, the oil shale zone is prepared by various fracturing techniques to create permeability, and no mining is involved. This is in contrast to the modified in-situ process, which involves underground mining of 20 to 25% of the shale deposit (or barren rock above and/or below the shale deposit), followed by explosive fracturing of the shale into the void volume to create a chimney of rubblized shale. Retorting of the shale can be carried out in either the vertical or horizontal direction, depending on the thickness of the shale zone. The heat for retorting can be supplied by combustion of the shale in place or by the injection of externally heated gases.

There is published information on each of the eight selected processes. The available technical details vary considerably and it was determined that individual contacts would be made with each of the developers to obtain the latest information whenever possible. These contacts were in the form of conferences with technical and management personnel at corporate offices, together with laboratory and plant visits wherever permission could be secured. Finally, unpublished report sources were consulted, to the extent available, as an information cross-check on the above, providing that the proprietary nature of any data obtained was properly treated.

The process overview reports are not intended to provide in-depth analysis, but to supply useful and accurate background information on recovery technologies. The reports attempt to include:

- general process description
- shale preparation requirements
- equipment types
- operating conditions (e.g., temperature, feed rate)
- Physical and chemical characteristics of process products and by-products
- energy and water requirements
- process stream characteristics

- retorted shale disposal requirements
- site-specific aspects, wherever applicable

Each of the reports was submitted to the respective process developers for review relative to accuracy and conformance to current planning. TRW and the Denver Research Institute appreciate the helpful comments provided by many developers.

UNION OIL SHALE RETORTING PROCESS

C. C. Shih

The Union Oil Company of California (Union) has been involved in oil shale activities for more than fifty years. During that time it has acquired 121 Mm^2 (30,000 acres) of property located on the Parachute Creek, north of Grand Valley, Colorado (Figure 1).† The development of Union's oil shale retorting technology was initiated in the early 1940's, and several variations of a vertical kiln retorting process, with upward flow of shale and countercurrent downward flow of gases and liquids, have been developed. Two variations are known as the Retort A and the Retort B. The first concept, the Retort A process, has been carried through 1.81 tonnes†† (2 tons) per day and 45.4 tonnes (50 tons) per day pilot plants. This was followed by the construction and operation of a large demonstration plant in the late 1950's. The demonstration plant was designed for 317.5 tonnes (350 tons) per day capacity, but long-term operability was demonstrated at rates of 635 to 907 tonnes (700 to 1,000 tons) per day, with a peak rate of 1,089 tonnes (1,200 tons) per day. However, although the demonstration of the Retort A process was extensive and successful, the Union Oil work, except for a continuing low activity research effort, was suspended due to the plentiful supply of low-cost Middle East oil and natural gas at the time. An improved version of the Union Oil process, the Retort B process, was developed in subsequent work in response to the increasing energy demands and shortage of fuel supplies, and has been carried through pilot plant stage. It is the Retort B process that Union Oil now proposes to construct and demonstrate at the 9,072 tonnes (10,000 tons) per day rate along with all necessary auxiliary facilities.

UNDERGROUND MINING AND CRUSHING

Union Oil proposes to utilize the conventional room-and-pillar method for production mining, with the mine portal designed to open on to a bench at the 2,100 m (7,000 ft) elevation. The rooms will be 18.3 m (60 ft) high by 18.3 m (60 ft) wide and the pillars will have an 18.3 m (60 ft) square horizontal section. The initial production mining will be at a rate of approximately 9,900 tonnes (10,900 tons) per stream day.

Both primary and secondary crushing of the shale ore will be done underground. Primary crushing will reduce the size of the run-of-mine shale to minus 20 cm (8 in), and secondary crushing will further reduce the shale size

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†A second fee property owned by Union Oil, also shown in Figure 1, consists of 5,200 acres. This property is probably of minor importance in Union's plans for commercial development.

††1 tonne = 1,000 kg

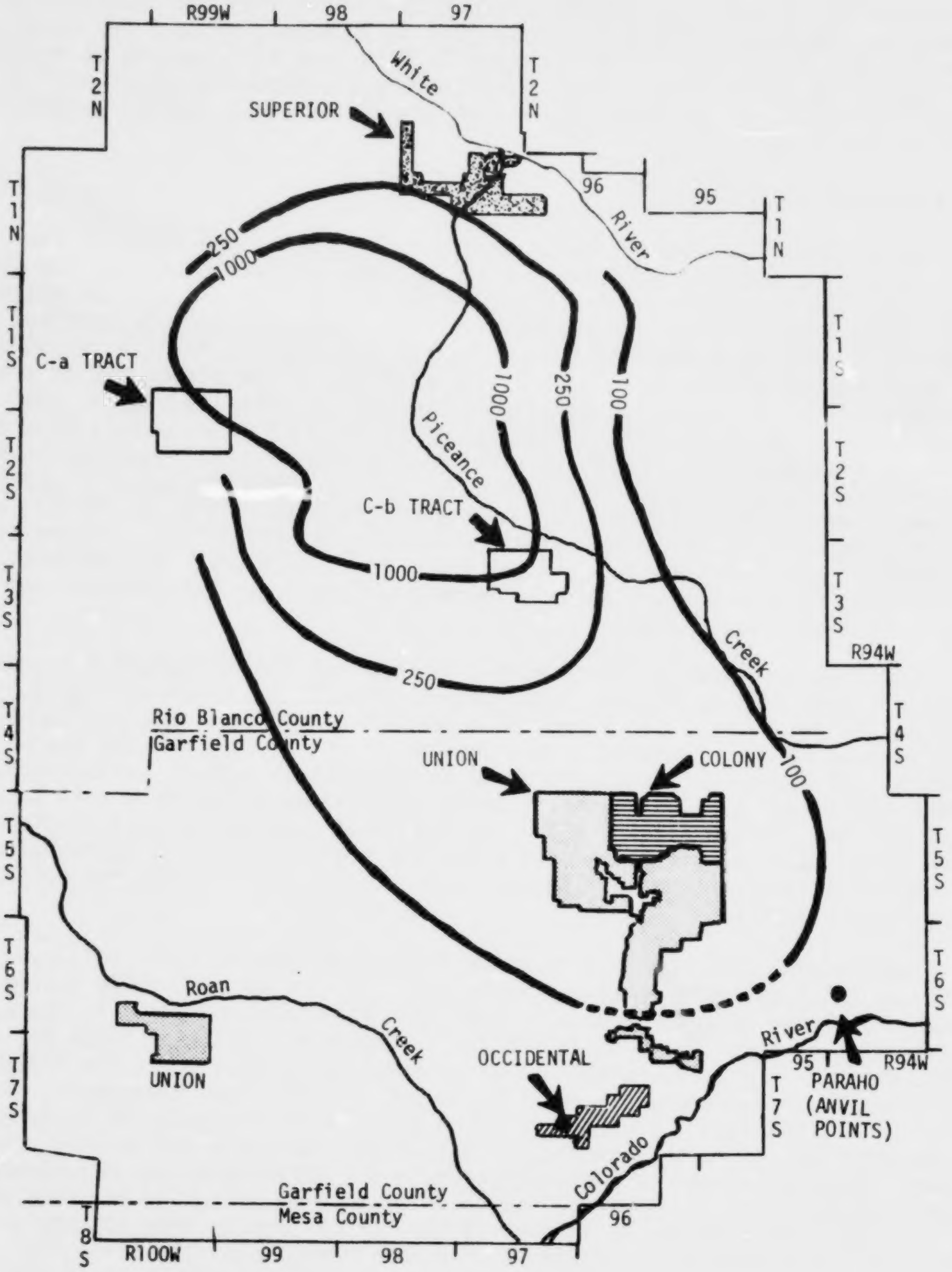

R99W
98
97
T 2 N
T 2 N
White
SUPERIOR
96
95
River
T 1 N
T 1 N
250
1000
T 1 S
T 1 S
C-a TRACT
1000
250
100
T 2 S
T 2 S
Piceance
C-b TRACT
1000
T 3 S
T 3 S
Creek
R94W
250
Rio Blanco County
Garfield County
T 4 S
T 4 S
UNION
COLONY
100
T 5 S
T 5 S
T 6 S
T 6 S
Roan
Creek
River
95
R94W
UNION
OCCIDENTAL
T 7 S
T 7 S
PARAHO (ANVIL POINTS)
Colorado
Garfield County
Mesa County
96
T 8 S
R100W
99
98
97

Figure 1. Union Oil Shale Fee Property in Piceance Creek Basin, Colorado.

to minus 5 cm (2 in). The crusher product is divided into two fractions by screening. Shale particle size in the 0.32 to 5.08 cm (1/8 to 2 in) range is used for the retort feed. The less than 0.32 cm (1.8 in) fraction is rejected and stockpiled in the mine. Dusts from the shale preparation plant will be controlled by the use of dust suppression systems and dust removal systems such as bag filters.

RETORTING AND UPGRADING

In the Retort B process, shown in Figure 2, crushed oil shale in the 0.32 to 5.08 cm (1/8 to 2 in) size range flows through two feed chutes to the solids pump. The solids pump consists of two piston and cylinder assemblies which alternately feed shale to the retort, and is mounted on a movable carriage and completely enclosed within the feeder housing and immersed in oil. As shale is moved upward through the retort by the upstroke of the piston, it is met by a stream of 510 to 538°C (950 to 1000°F) recycle gas from the recycle gas heater flowing downward. The rising oil shale bed is heated to retorting temperature by countercurrent contact with the hot recycle gas, resulting in the evolution of shale oil vapor and make gas. This mixture of shale oil vapor and make gas is forced downward by the recycle gas, and cooled by contact with the cold incoming shale in the lower section of the retort cone. In the disengaging section surrounding the lower cone, the liquid level is controlled by withdrawing the oil product, and the recycle and make gas are removed from the space above the liquid level.

The flow diagrams for the Retort B process and for the Retort B prototype plant are presented in Figures 3, 4, 5A, 5B, and 5C. As shown in Figures 3 and 5A, the make gas is first sent to a Venturi scrubber for cooling and heavy ends removal by oil scrubbing. That portion of the 31.5 MJ/m^3 (800 Btu/SCF) make gas not recycled is then processed by compression and oil scrubbing to remove additional naphtha and heavy ends, followed by a Stretford unit to remove hydrogen sulfide (Figure 5C). The sweetened make gas is used as plant fuel. The remaining gas, taken off after the venturi scrubber, is recycled to the retort through the recycle gas heater to provide the heat for oil shale retorting (Figure 5A).

The rundown oil from the retort is treated sequentially for solids, arsenic, and light ends removal (Figure 5B). The solids removal is accomplished by two stages of water washing. The shale fines are collected in the water phase which is recycled to the water seal. The water seal is a Union Oil concept, shown in Figure 3, in which a water level is maintained in the conveyer for retorted shale removal to seal the retort pressure from atmosphere. For arsenic (As) removal, a proprietary Union Oil process employing an adsorbent is utilized to reduce the arsenic content of the raw shale oil from 50 ppm to 2 ppm. Arsenic removal is necessary because the presence of the relatively high concentration of arsenic in the crude shale oil (50 ppm As in crude shale oil vs less than 0.03 ppm As in conventional crudes) would lead to catalyst deactivation in both hydrotreating and in subsequent catalytic reforming. The dearsenated shale oil is sent to a stripping column for stabilization and stripping prior to shipment. This partially upgraded shale oil can now be marketed as a low sulfur burner fuel in various locations in the United States, and is also a suitable feedstock for refineries that have adequate hydrotreating capacity. It may be noted that rather severe hydrotreating conditions are required to reduce the high level of nitrogen in the crude shale oil to the low levels acceptable for reforming. At the present time, however, Union Oil does not envision additional upgrading of the crude shale oil on-site.

For the Retort B prototype plant, the principal pollution control devices in the Union Oil design include the Stretford process for hydrogen sulfide removal from the retort make gas and oil/water separation and sour water stripping for wastewater treatment. The treated wastewater is used in the cooling and moistening of the retorted shale to provide for dust control and proper compaction. Dust control is also provided throughout the plant wherever emission might be encountered.

The crude shale oil from the Retort B process has a specific gravity of 0.918 (22.7°API), a pour point of 15.6°C (60°F), and a kinematic viscosity of 20 centistokes (98.2 SUS) at 37.8°C (100°F). It typically contains 1.74 weight percent nitrogen and 0.81 weight percent sulfur. Its Conradson carbon residue (1.75%) is lower than that of the Paraho or TOSCO shale oils (5%). Union Oil indicates that a better quality crude shale oil is obtained in the Retort B process because oil vapor evolved in the retort is quickly forced downward by the gas toward the cooler shale, thus quenching the polymerization reactions which form heavy oil that is difficult to refine. In addition, the use of an indirectly heated recycle gas in the Retort B process appears to result in a crude shale oil of lower oxygen content. This is desirable because the presence of oxygen compounds has been known to contribute to gum formation and enhance corrosion rates in certain situations.

The Retort A process uses similar equipment required in the Retort B process. The main difference between the Retort A and Retort B processes is that hot gases, generated by burning the carbonaceous deposit on the retorted shale in the upper part of the retort, is used to cause oil shale pyrolysis in the Retort A process. The Retort B process is selected over the Retort A process because higher yields of a better quality shale oil and a high Btu gas product are obtained with the Retort B process.

RETORTED SHALE DISPOSAL

The retorted shale from the Retort B process is similar to that produced by the Bureau of Mines and Paraho retorting processes. It is a coarse gravel-sized material with some black carbonaceous residue remaining on the shale. The retorted shale will be cooled and moistened by the treated waste water prior to disposal. The retorted shale slurry has a pH of 8.7 and very little tendency for cementation. For the prototype plant, 7,620 tonnes (8,397 tons) per day (dry basis) of retorted shale containing approximately 20 percent water will be transported to a disposal area in the East Parachute Creek Canyon, where it will be laid down and compacted in windrows proceeding up the south embankment. The embankment will be provided with a leachate collection ditch, so that any leachates resulting from rain and snow melt runoff will be gathered and discharged into the plant water supply pond. In addition, a cutoff trench will be constructed immediately downstream of the plant water supply pond to bed rock so as to help collect subsurface flow of any leachates. Thus, all process wastewater, as well as any retorted shale embankment runoff, will be collected in the plant water pond .

Union Oil is currently investigating revegetation on retorted shale plots. The results, based upon initial germination, appear to be favorable.[†] For the prototype plant, Union Oil plans a revegetation program which includes mulching, seeding, irrigation, and fertilization.

OIL SHALE RETORTING PRODUCTS AND UTILITIES REQUIREMENTS

For a commercial size plant processing 57,620 tonnes (63,500 tons) of 34 gpt oil shale per stream day, the Union Retort B process will generate the following products:

Crude shale oil: 7,950 m^3 (50,000 bbl) per stream day

Sulfur: 51 tonnes (56 tons) per stream day[††]

Retorted shale (dry basis): 47,800 tonnes (52,680 tons) per stream day

Wastewater (contained in the retorted shale): 498 m^3/hr (2,190 gpm)

The total water consumption rate is estimated by Union Oil to be 585 m^3/hr (2,580 gpm) and the power requirement to be 70,000 kw. The fuel requirements for the plant will be met by the retort make gas produced.

[†] Lipman, S. C., "Union Oil Revegetation Studies," paper presented at the Environmental Oil Shale Symposium, Colorado School of Mines, October 9-10, 1975.

[††] This sulfur production rate, supplied by Union Oil, appears to be low. TRW estimates a sulfur production rate of 120 tonnes (132 tons) per stream day based on TOSCO II retorting process gas product composition.

Note: Figures 2 and 3 are from the paper "Development of Union Oil Company Upflow Retorting Technology" by J. M. Hopkins, H. C. Huffman, A. Kelley and J. R. Pownall, presented at the 81st AIChE National Meeting, April 11-14, 1976, Kansas City, Missouri

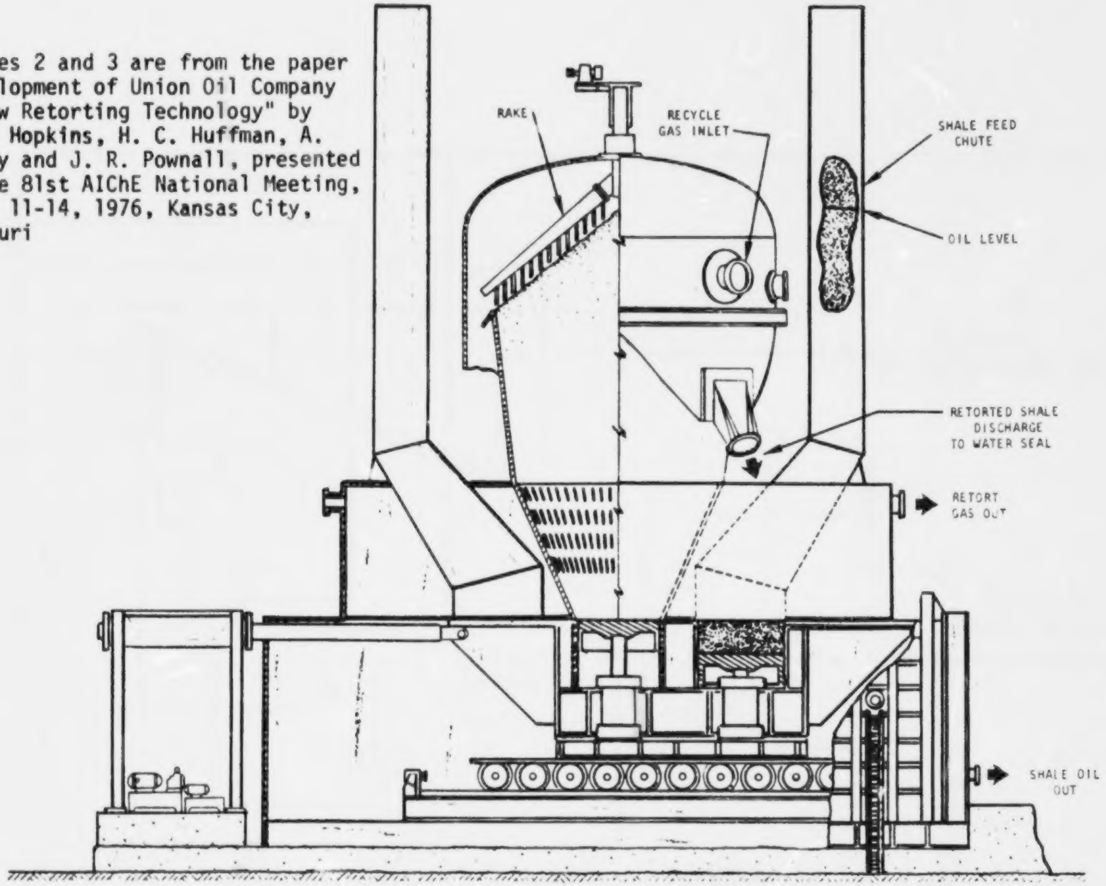

RAKE
RECYCLE GAS INLET
SHALE FEED CHUTE
OIL LEVEL
RETORTED SHALE DISCHARGE TO WATER SEAL
RETORT GAS OUT
SHALE OIL OUT

Figure 2. Union Retort B

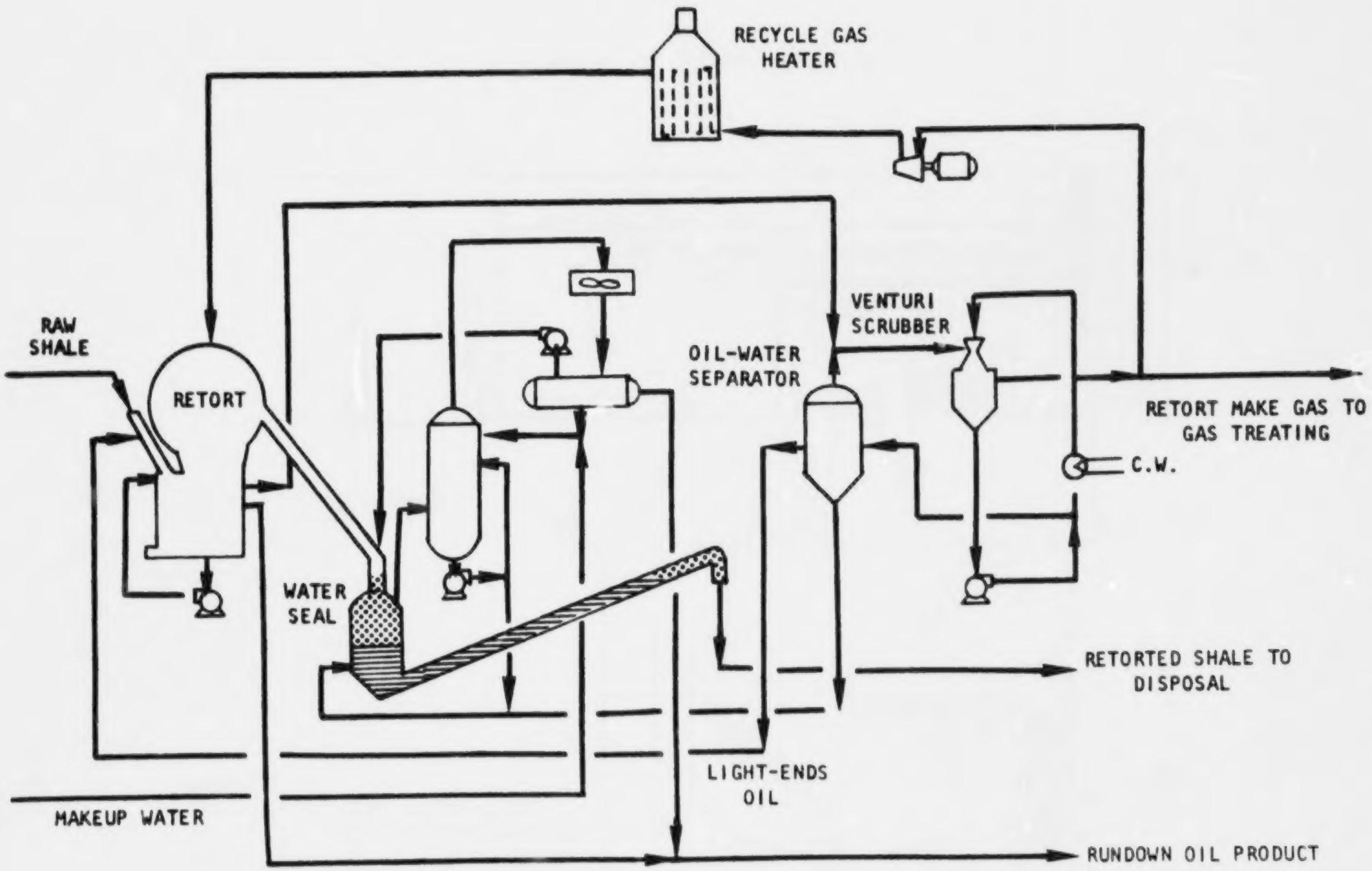
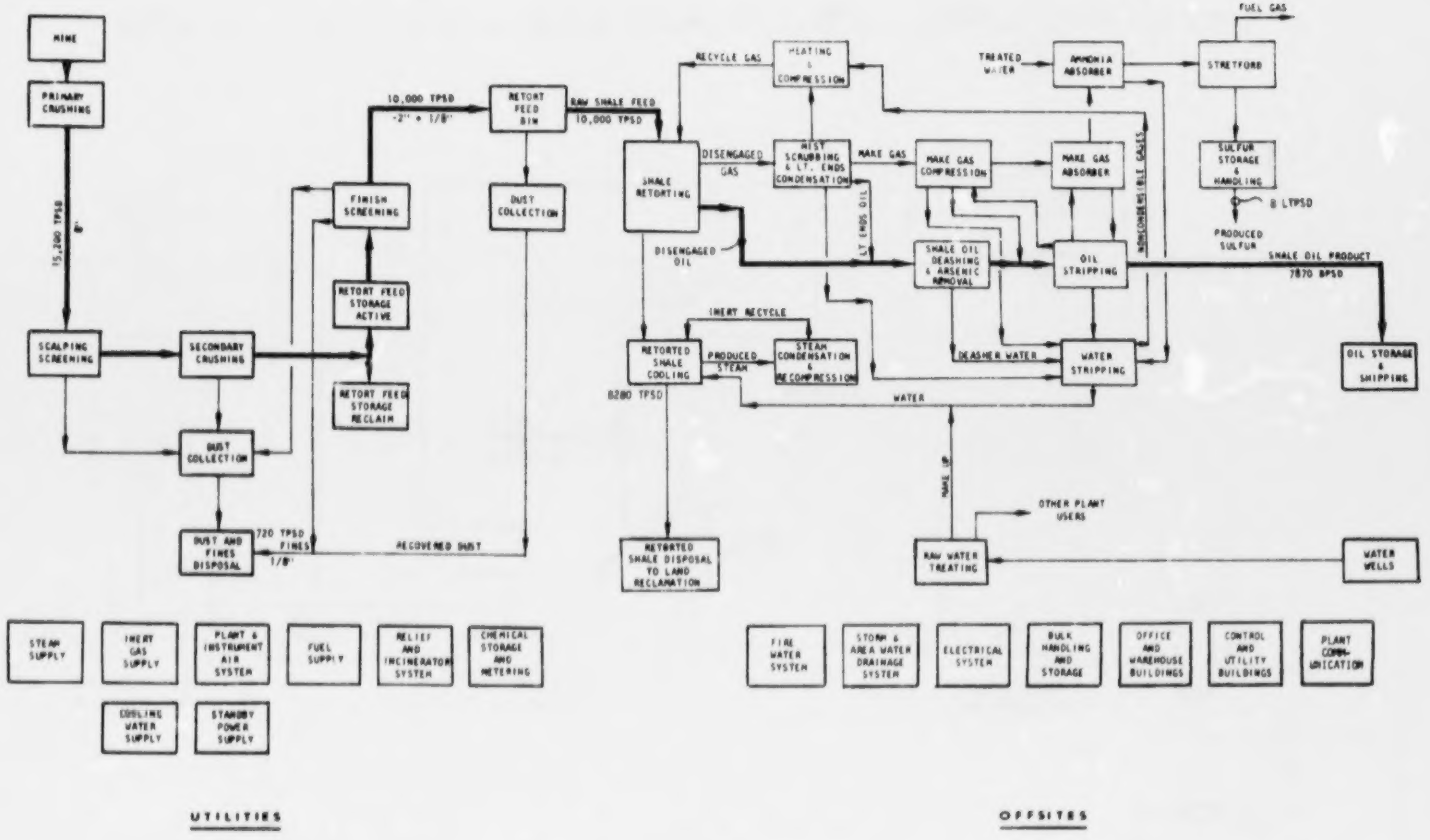

RECYCLE GAS HEATER
RAW SHALE
RETORT
VENTURI SCRUBBER
OIL-WATER SEPARATOR
RETORT MAKE GAS TO GAS TREATING
C.W.
WATER SEAL
RETORTED SHALE TO DISPOSAL
LIGHT-ENDS OIL
MAKEUP WATER
RUNDOWN OIL PRODUCT

Figure 3. Union Retort B Flow Diagram.


MINE
PRIMARY CRUSHING
15,200 TPSD
8"
SCALPING SCREENING
SECONDARY CRUSHING
DUST COLLECTION
DUST AND FINES DISPOSAL
720 TPSD FINES
1/8"
FINISH SCREENING
RETORT FEED STORAGE ACTIVE
RETORT FEED STORAGE RECLAIM
10,000 TPSD
-2" + 1/8"
RETORT FEED BIN
DUST COLLECTION
RECOVERED DUST
RAW SHALE FEED
10,000 TPSD
SHALE RETORTING
RECYCLE GAS
HEATING & COMPRESSION
DISENGAGED GAS
MIST SCRUBBING & LT. ENDS CONDENSATION
MAKE GAS
MAKE GAS COMPRESSION
MAKE GAS ABSORBER
TREATED WATER
AMMONIA ABSORBER
STRETFORD
FUEL GAS
SULFUR STORAGE & HANDLING
8 LTPSD
PRODUCED SULFUR
NONCONDENSIBLE GASES
LT ENDS OIL
DISENGAGED OIL
SHALE OIL DEASHING & ARSENIC REMOVAL
OIL STRIPPING
SHALE OIL PRODUCT
7870 BPSD
OIL STORAGE & SHIPPING
INERT RECYCLE
RETORTED SHALE COOLING
8280 TPSD
PRODUCED STEAM
STEAM CONDENSATION & RECOMPRESSION
DEASHER WATER
WATER STRIPPING
WATER
MAKE UP
OTHER PLANT USERS
RAW WATER TREATING
WATER WELLS
RETORTED SHALE DISPOSAL TO LAND RECLAMATION
STEAM SUPPLY
INERT GAS SUPPLY
PLANT & INSTRUMENT AIR SYSTEM
FUEL SUPPLY
RELIEF AND INCINERATOR SYSTEM
CHEMICAL STORAGE AND METERING
COOLING WATER SUPPLY
STANDBY POWER SUPPLY
FIRE WATER SYSTEM
STORM & AREA WATER DRAINAGE SYSTEM
ELECTRICAL SYSTEM
BULK HANDLING AND STORAGE
OFFICE AND WAREHOUSE BUILDINGS
CONTROL AND UTILITY BUILDINGS
PLANT COMMUNICATION
UTILITIES
OFFSITES

Note: Figures 4 and 5 are supplied by the Union Oil Company.

Figure 4. Block Flow Diagram for Union Oil Retort B Prototype Plant.

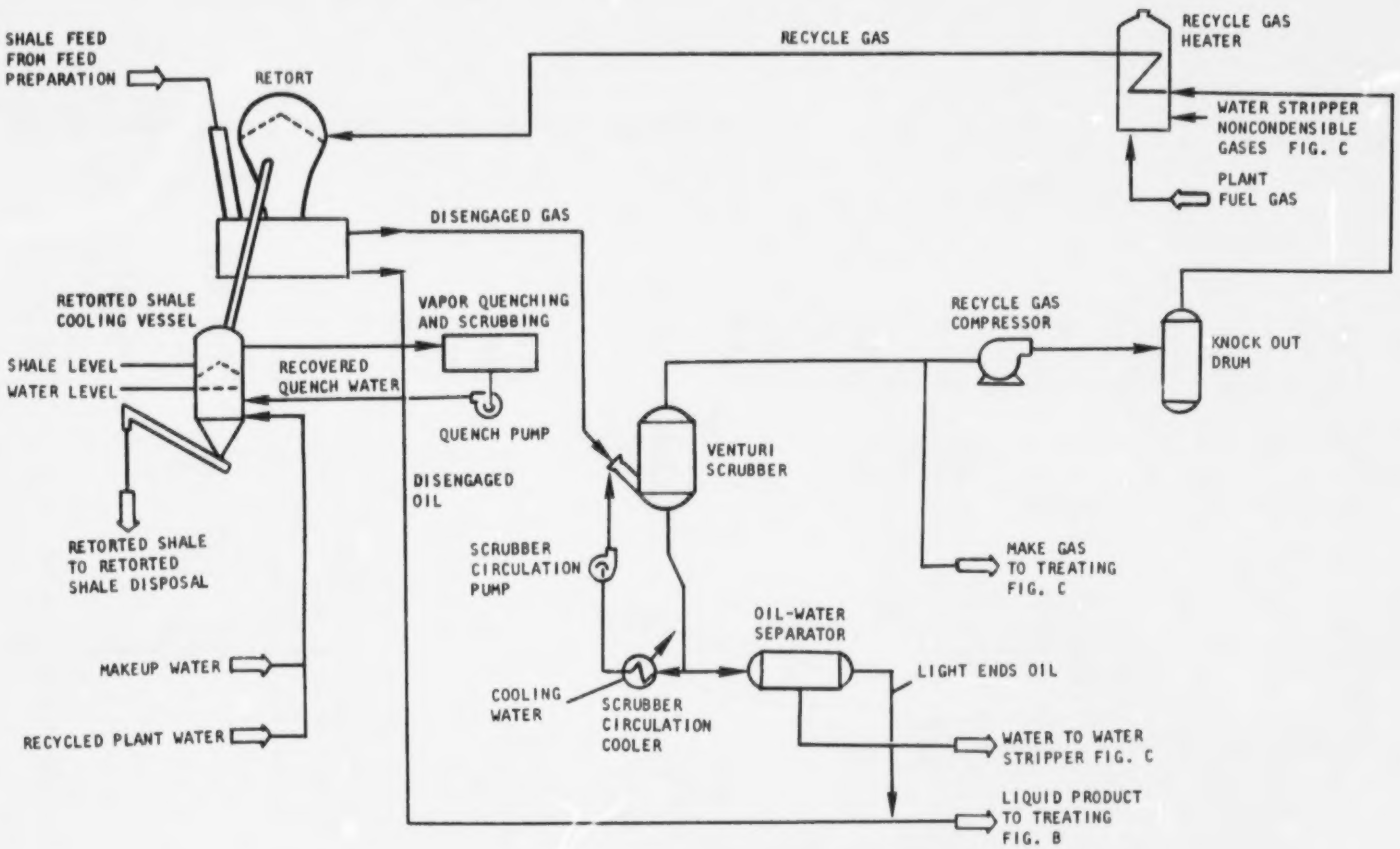

SHALE FEED FROM FEED PREPARATION
RETORT
RECYCLE GAS
RECYCLE GAS HEATER
WATER STRIPPER NONCONDENSIBLE GASES FIG. C
PLANT FUEL GAS
DISENGAGED GAS
RETORTED SHALE COOLING VESSEL
VAPOR QUENCHING AND SCRUBBING
SHALE LEVEL
WATER LEVEL
RECOVERED QUENCH WATER
QUENCH PUMP
RECYCLE GAS COMPRESSOR
KNOCK OUT DRUM
VENTURI SCRUBBER
DISENGAGED OIL
RETORTED SHALE TO RETORTED SHALE DISPOSAL
SCRUBBER CIRCULATION PUMP
MAKE GAS TO TREATING FIG. C
OIL-WATER SEPARATOR
MAKEUP WATER
LIGHT ENDS OIL
COOLING WATER
SCRUBBER CIRCULATION COOLER
RECYCLED PLANT WATER
WATER TO WATER STRIPPER FIG. C
LIQUID PRODUCT TO TREATING FIG. B

Figure 5A. Flow Diagram for Retort System in Union Oil Retort B Prototype Plant.

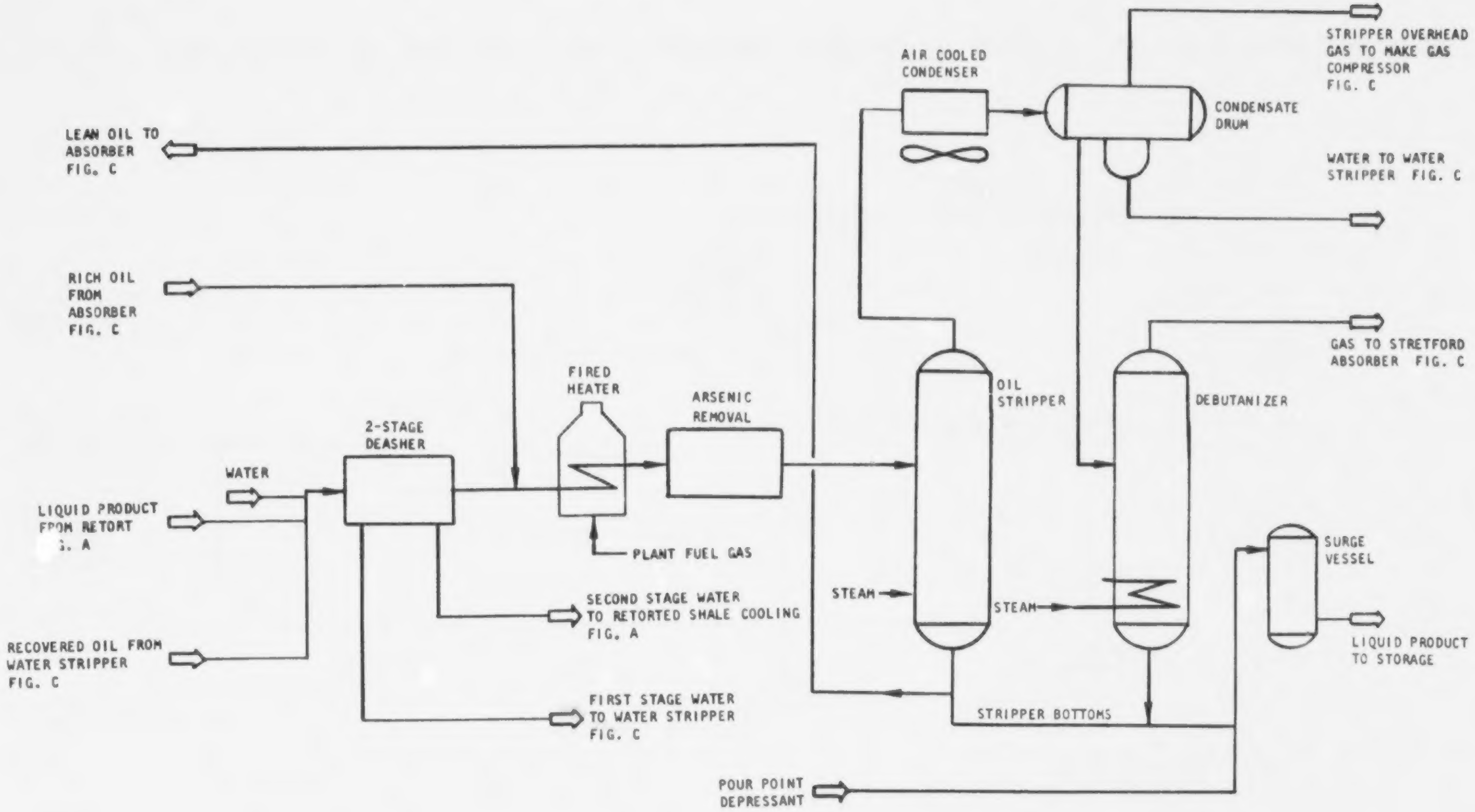

STRIPPER OVERHEAD GAS TO MAKE GAS COMPRESSOR FIG. C
AIR COOLED CONDENSER
CONDENSATE DRUM
WATER TO WATER STRIPPER FIG. C
LEAN OIL TO ABSORBER FIG. C
RICH OIL FROM ABSORBER FIG. C
GAS TO STRETFORD ABSORBER FIG. C
FIRED HEATER
ARSENIC REMOVAL
OIL STRIPPER
DEBUTANIZER
2-STAGE DEASHER
WATER
LIQUID PRODUCT FROM RETORT [illegible]. A
PLANT FUEL GAS
SURGE VESSEL
SECOND STAGE WATER TO RETORTED SHALE COOLING FIG. A
STEAM
STEAM
LIQUID PRODUCT TO STORAGE
RECOVERED OIL FROM WATER STRIPPER FIG. C
FIRST STAGE WATER TO WATER STRIPPER FIG. C
STRIPPER BOTTOMS
POUR POINT DEPRESSANT

Figure 5B. Flow Diagram for Shale Oil Processing in Union Oil Retort B Prototype Plant.

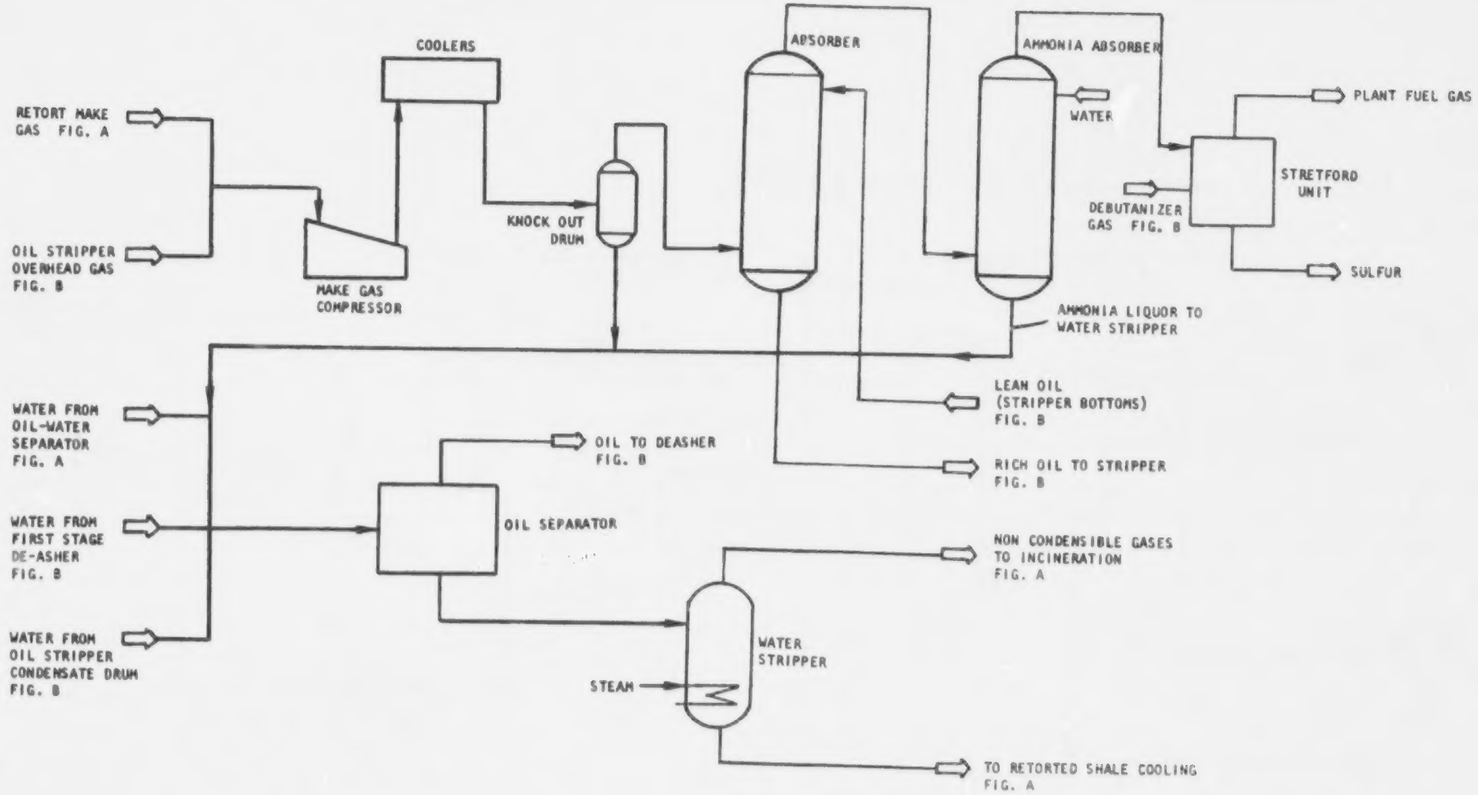

RETORT MAKE GAS FIG. A
OIL STRIPPER OVERHEAD GAS FIG. B
MAKE GAS COMPRESSOR
COOLERS
KNOCK OUT DRUM
ABSORBER
AMMONIA ABSORBER
WATER
STRETFORD UNIT
PLANT FUEL GAS
DEBUTANIZER GAS FIG. B
SULFUR
AMMONIA LIQUOR TO WATER STRIPPER
LEAN OIL (STRIPPER BOTTOMS) FIG. B
RICH OIL TO STRIPPER FIG. B
WATER FROM OIL-WATER SEPARATOR FIG. A
OIL TO DEASHER FIG. B
WATER FROM FIRST STAGE DE-ASHER FIG. B
OIL SEPARATOR
NON CONDENSIBLE GASES TO INCINERATION FIG. A
WATER FROM OIL STRIPPER CONDENSATE DRUM FIG. B
WATER STRIPPER
STEAM
TO RETORTED SHALE COOLING FIG. A

Figure 5C. Flow Diagram for Fuel Gas Process and Water Treatment in Union Oil Retort B Prototype Plant.

PARAHO OIL SHALE PROCESS

T. D. Nevens, C. H. Prien

The Paraho Oil Shale Process is based on a series of patents and inventions by John B. Jones, Development Engineering, Inc. (DEI). The retorting technology is the outgrowth of research extending over many years on (a) the pyrolysis of both Colorado and Brazilian oil shales, and (b) the calcination of both high calcium and dolomitic limestones.

BACKGROUND

In 1972, Development Engineering, Inc. obtained a long-term lease on the U.S. Department of Interior/Navy oil shale plant and mining facilities at Anvil Points in order to prove the DEI technology. The Paraho Development Corporation was formed with DEI as a subsidiary, and the Paraho Oil Shale Project was launched in late 1973 with funds provided by 17 participating companies,† including many with long experience in oil shale research. DEI continued as the operating company, and Arthur G. McKee and Co. was selected as engineering contractors.

Two newly designed Paraho oil shale retorts were constructed at Anvil Points, and placed in operation in 1974. These included a 1.4 meter (4.5 ft) O.D. pilot plant used for rapid investigation of operating parameters, and a 3.2 meter (10.5 ft) O.D. semi-works unit with a nominal throughput capacity of 408 tonnes (450 tons) per day for large-scale testing under production conditions. The oil shale retorts were based on a DEI design used successfully for lime burning, where throughput rates of up to 635 tonnes (700 tons) per day have been attained.

The two retorts have been operated on an intermittent basis from mid-1974 to mid-1976 as part of a continuing $9 million Paraho project to determine design parameters for scale-up to a commercial plant. During one 56-day semicontinuous run of the semi-works plant in 1975, using a direct-heating mode†† some 1600 cubic meters (10,000 barrels) of shale oil were produced. The Navy had the oil refined into seven different fuels by the Gary Western Refinery near Grand Junction, Colorado.

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†The seventeen Paraho participants are Atlantic Richfield, Carter Oil (Exxon), Chevron Research (Std. of California), Cleveland-Cliffs Iron Co., Gulf Oil, Kerr-McGee, Marathon Oil, Arthur G. McKee, Mobil Research, Phillips Petroleum, Shell Development, Sohio Petroleum, Southern California Edison, Standard Oil Co., (Indiana), Sun Oil, Texaco, Webb-Chambers-Gary-McLoraine Group.

††A description of direct and indirect heating modes is given in the subsequent section on retorting.

The program on the semi-works retort direct-heated mode of operation was completed in November 1975. Oil yields varied from 94% to 97% of Fischer assay. The pilot plant retort has continued operation in the direct mode primarily to provide a source of low-Btu gas for subsequent indirect-mode operation of the semi-works retort.

The semi-works retort was converted to indirect-mode heating in December 1975, and a 30-day run completed in February 1976. Yields of up to 97% Fischer assay were obtained during a 12-day "confirmation run."

It was planned to carry out further development of the Paraho process in 1977 under a proposed $12-$15 million ERDA/Navy appropriation. An Environmental Impact Statement was completed for the construction of a full-scale 11,800 tonnes (13,000 tons) per day modular Paraho retort and supporting facilities.

PARAHO DEMONSTRATION PROJECT

The present Paraho oil shale demonstration project utilizes some of the facilities originally developed by the U.S. Bureau of Mines at Anvil Points, including an underground room and pillar mine, crushing plant, retort structure, various storage tanks, shale disposal area, and associated laboratories, maintenance shops, and water supplies.

Underground Mining, Crushing

The mine at Anvil Points is a room and pillar operation encompassing the Mahogany Ledge of the Green River Formation at an altitude of approximately 2440 meters (8000 ft). Mined shale is trucked approximately 8.8 kilometers (5.5 miles) to the processing area, at an elevation of about 6000 feet. Through 1976 over 75,000 tons of oil shale had been mined by Paraho, of which more than 80% had been sent through the Paraho retorts.

At the plant site the mined shale is processed through the primary and secondary circuits of the USBM crushing and screening plant to produce a feed of approximately minus 7.6 cm (3 in) plus 6 mm (¼ in) size, which is sent to storage bins. The 10-15% fines from the screening plant are stockpiled.

Retorting Plant, Auxiliary Facilities

Two Paraho-type retorts (Figure 6) have been erected in a steel structure adjacent to the old USBM gas combustion unit. These include a 1.4 meter (4.5 ft) O.D. (2.5 ft I.D.) by 18 meters (60 ft) high pilot plant unit, and a semi-works retort which is 3.2 meters (10.5 ft) O.D. (8.5 ft I.D.) by 23 meters (75 ft) high. To avoid flaring retort make gases, the old USBM gas combustion unit has been converted to a thermal oxidizer.

Provision has been made for operating the retorts in either the direct mode or indirect mode. In the direct mode (Figure 7) the carbonaceous residue on the retorted shale is burned in the combustion zone to provide the principal fuel for the process. Low Btu retort gases are recycled to both the combustion zone and the residue cooling and gas preheating zone. A typical retort temperature profile for this mode of operation is shown in Figure 8.

*from Jones, John B., "The Paraho Oil Shale Retort", 81st Nat. Mtg., AIChE, Kansas City, Mo., April 11-14, 1976.

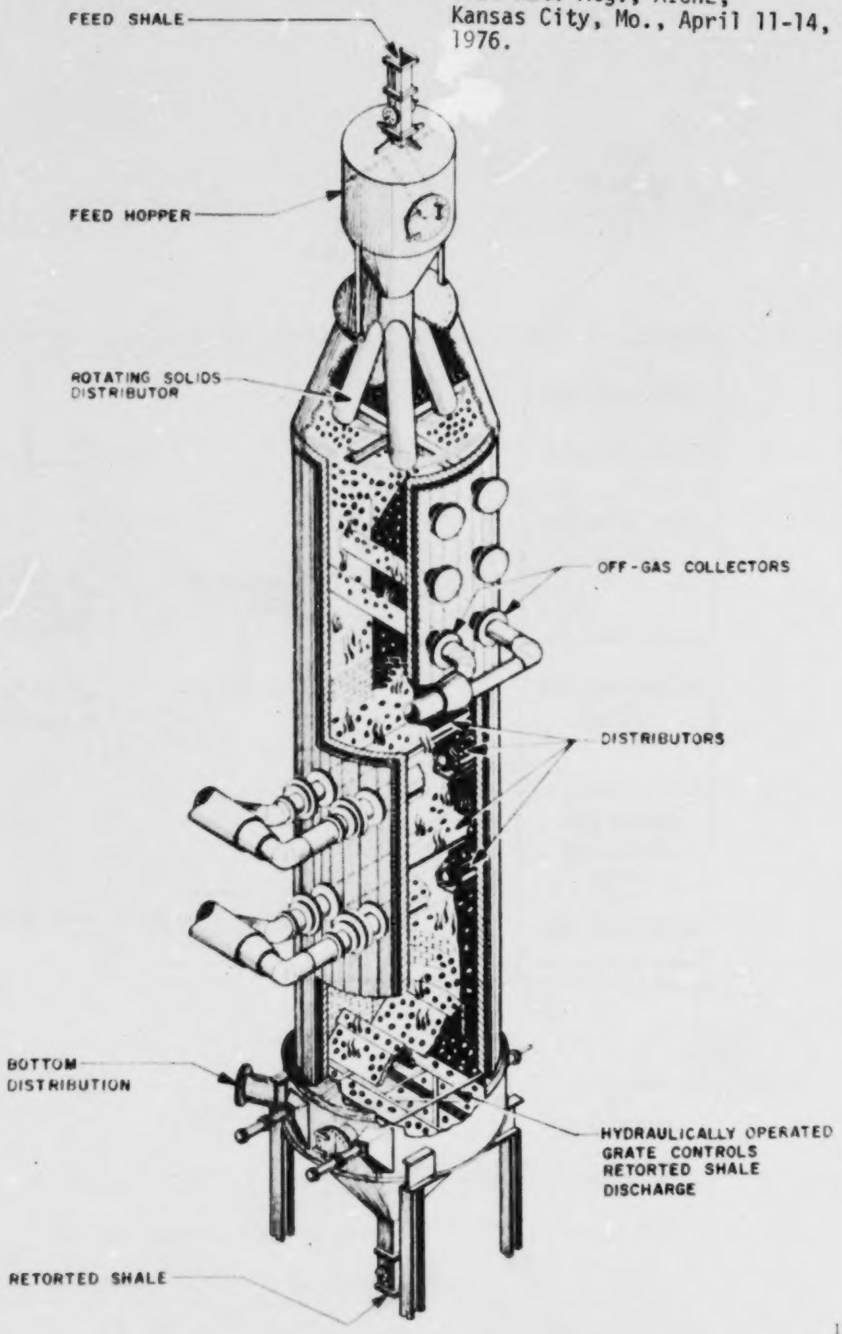

FEED SHALE
FEED HOPPER
ROTATING SOLIDS DISTRIBUTOR
OFF-GAS COLLECTORS
DISTRIBUTORS
BOTTOM DISTRIBUTION
HYDRAULICALLY OPERATED GRATE CONTROLS RETORTED SHALE DISCHARGE
RETORTED SHALE

Figure 6. The Paraho Retort.*

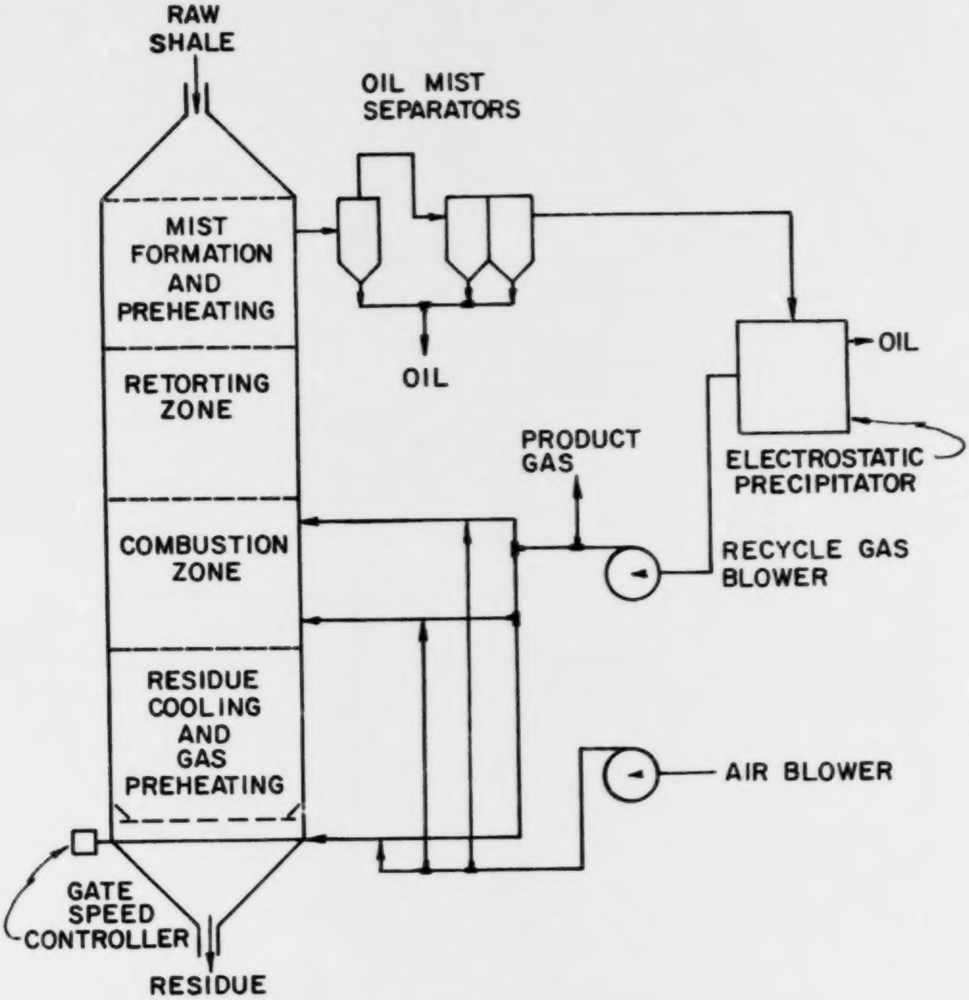
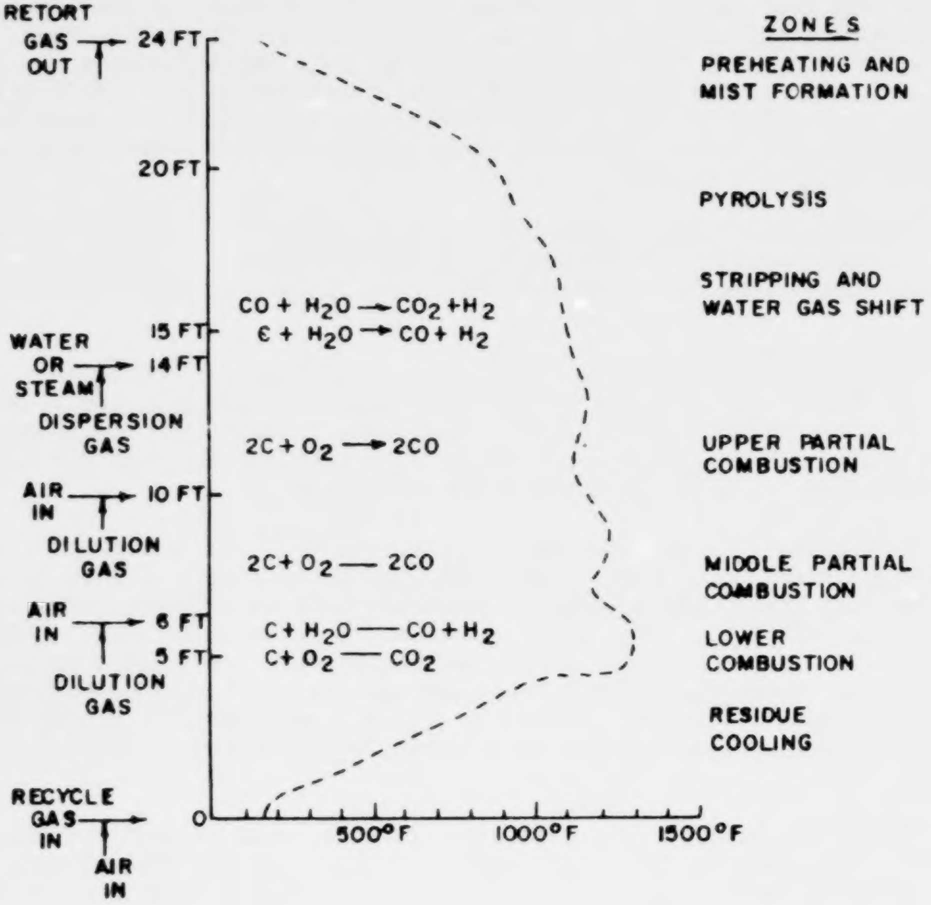

RAW SHALE
OIL MIST SEPARATORS
MIST FORMATION AND PREHEATING
RETORTING ZONE
OIL
OIL
ELECTROSTATIC PRECIPITATOR
PRODUCT GAS
COMBUSTION ZONE
RECYCLE GAS BLOWER
RESIDUE COOLING AND GAS PREHEATING
AIR BLOWER
GATE SPEED CONTROLLER
RESIDUE

Figure 7. Paraho Direct Mode Flow Diagram.



*from U.S. Patent 3,736,247.

Figure 8. Temperature Profile in Paraho Direct Mode Retort.*

In the indirect mode (Figure 9) heat for retorting is supplied by hot retort gases from an outside furnace, thus eliminating combustion in the retort and producing a high heating value, 8000 kcal/std cu meter (900 Btu/SCF) off-gas.

In either mode of operation (Figures 7 and 9), raw shale is fed into the top of a Paraho retort by means of a rotary pant-leg distributor, and passes downward by gravity successively through a mist formation and preheating zone, a retorting zone, either a combustion zone (direct mode) or heating zone (indirect mode), and finally, a residue cooling and gas preheating zone. It is discharged through a hydraulically-operated grate which controls the desirable downward velocity and maintains even flow across the retort. This grate, the rotary feed mechanism, and the multi-levels of heat input are among the unique contributions of Paraho technology toward improving the retorting principle in vertical kiln type retorts.

The retorted shale, containing about 2% carbon (direct mode) to 4.5% carbon (indirect mode), is discharged from the retort at about 150°C (300°F). It is then sent to the shale disposal area originally developed by the Bureau of Mines.

The shale vapors produced in the retorting zone are cooled to a stable mist by the incoming raw shale (which is thereby preheated), and leave the retort at approximately 60°C (140°F). This mist is sent to a roughing cyclone, a condenser, and finally a wet electrostatic precipitator, for oil separation. The resulting shale oil is transported to storage.

In the direct mode, the remaining cooled, oil-free retort gases (approximately 908 kcal/std cu meter (103 Btu/SCF) are, in part, recycled to the retort (Figure 7). The remaining product gases are sent to a thermal oxidizer without treatment for H_2S or NH_3 removal, and the resulting flue gases vented to the atmosphere. In a commercial size plant the product gases would be processed, as required, to be H_2S and NH_3 free, and used as plant fuel or for power generation in low-Btu turbines. From 116 liters/tonne (28 gal/ton) raw shale, there is produced some 193 std cubic meters/tonne (6,200 SCF/ton) of product gases.

The direct mode recycle gases are, in part, used to cool the retorted shale on the grate in the lower "residue cooling and gas preheating zone." The remaining recycle gases are used at several levels to dilute the air entering the retort for combustion.

In the indirect heating mode (Figure 9) the mist-laden off-gases leave the retort at 138°C (280°F). After oil separation, the oil denuded recycle gases have a high heating value, about 7,560 kcal/std cu meter (885 Btu/SCF). Part of these gases are reheated in an outside heater and distributed to the retort at several levels. It is these hot gases which supply the necessary heat for retorting the shale. No residual carbon on the retorted shale or gas is burned in the retort. There is, therefore, no dilution of off-gases with combustion products and resulting reduction in retort-gas heating value.

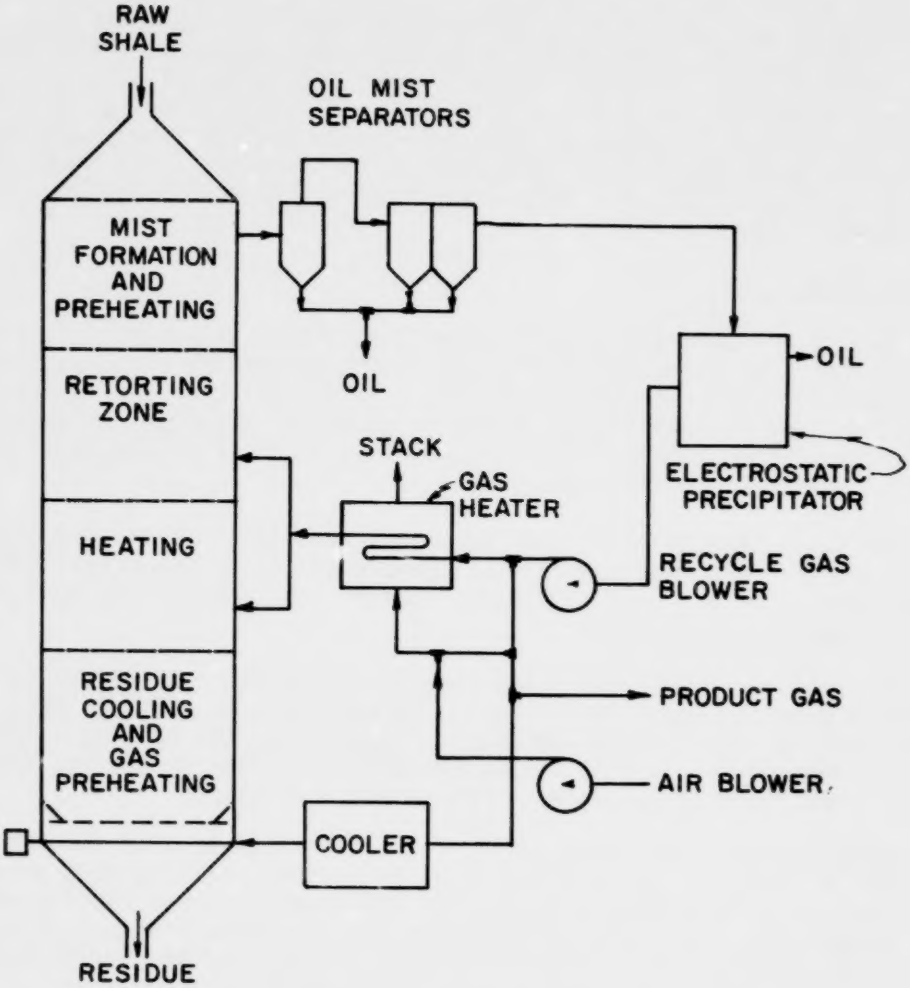

RAW SHALE
OIL MIST SEPARATORS
MIST FORMATION AND PREHEATING
OIL
RETORTING ZONE
OIL
STACK
GAS HEATER
ELECTROSTATIC PRECIPITATOR
HEATING
RECYCLE GAS BLOWER
RESIDUE COOLING AND GAS PREHEATING
PRODUCT GAS
AIR BLOWER
COOLER
RESIDUE

Figure 9. Paraho Indirect Mode Flow Diagram.

The fuel for the external, recycle-gas heater may be a side-stream of the recycle gas itself, or an outside fuel. Using recycle gas as fuel, there is produced some net 15.6 std cubic meters/tonne (500 SCF/ton) of high Btu product gas from a 116 liters/tonne (28 gal/ton) shale.

Semi-Works Plant Operating Characteristics

With the Paraho retort, higher throughput rates have been attained than with previous gas combustion retort designs. Mass rates of 2934 kg/hr sq meter retort cross-section (600 lbs/hr sq ft) have been attained in the semi-works plant, and 3423 kg/hr sq meter (700 lbs/hr sq ft) in the pilot plant retort. Carbonate decomposition has been essentially eliminated during indirect mode operation. During direct-mode operation there has been essentially no clinkering, a problem in earlier gas combustion retort designs. The shale passes through the retort without substantial change in size distribution (minimum production of fines).

Product Properties

Shale Oil. Selected properties of the Paraho shale oils from both direct and indirect mode operation in the semi-works retort are shown in Table 1. The direct mode oil has essentially the conventional characteristics of a gas-combustion-type raw shale oil. While no sulfur or nitrogen contents have been reported by Paraho, these could also be expected to be in the usual range for oil from internally-heated retorts.[†]

The indirect-mode Paraho oil has a somewhat lower pour point (18°C, 65°F), which has also been reported for the crude shale oils from other indirectly-heated retorts (e.g., Union (65°F)). Further lowering of this pour point would probably require coking.

As a result of the combustion zone in the direct mode retort the volume of retort gases produced in this mode, as expected, is 12 times that from indirect heating mode (see Table 2). Conversely, the heating value of the indirect mode gases, as a result of no combustion zone in the indirect retort, have 9 times the heating value of the direct mode gases.

Retort Gases. The composition of the retort gases from the two retorts is given in Table 2. It is noted that the indirect heating mode gases are much lower in carbon dioxide because of the lower indirect heating mode retort temperatures, but have substantially higher concentrations of H_2S and NH_3, in the absence of a combustion zone. The H_2S and NH_3 would obviously have to be reduced in all retort gases prior to their use as fuels. Data on such upgrading have not yet become available.

Retorted Shale. Paraho retorted shale has essentially the same size distribution as the raw shale feed (minus 3 in plus ¼ in). In addition to the

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[†] The White River Shale Project Detailed Development Plan (July 1976) reports 0.7 wt % S, 2.1 wt % N for a Paraho-type direct or indirect mode crude shale oil.

Demonstration Project disposal area at Anvil Points, a series of test plots for a research and development program on Paraho retorted shale has also been established. Although this study is still in progress some preliminary results have been published.[1] A series of lysimeter tests has also been initiated by Colorado State University.

Table 1. Paraho Shale Oil Properties*

Item	Heating Mode	
	Direct	Indirect
Gravity, A.P.I.	21.4	21.7
Viscosity, SUS @ 130°F	90	68
SUS @ 210°F	46	42
Pour Point °F	85	65
Ramsbottom carbon wt %	1.7	1.3
Water Content, vol %	1.5	1.4
Solids, B.S.,** wt %	.5	.6

Note: from semi-works retorting of the 116 liters/tonne (28 GPT) shale, at 97% Fischer assay yield.

*Jones, John B., "The Paraho Oil Shale Retort," 81st Nat. Mtg., A.I.Ch.E., Kansas City, Mo., April 11-14, 1976.

**B.S. (Basal Sediment)

Soluble salts in the processed shale are in the order of 2%; pH is 10.7 to 11.8, and electrical-conductivity is in the range 5 to 20 mmhos. It would appear from these data that the surface layer of the disposal pile will require leaching prior to revegetation. Other Paraho spent shale properties are shown in Table 3. It is noted that compaction densities of 1410-1570 kg/cubic meter (88-98 lbs/cu ft) have been readily attained in the disposal piles, at 22-23% H_2O.

FULL-SCALE COMMERCIAL MODULE

Over a four-year period Paraho has proposed the construction and operation of a full-scale single commercial module of a Paraho retort with a nominal throughput capacity of 11,800 tonnes (13,000 tons) per day. The retorting

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[1] Woodward-Clyde Consultants, "Research and Development Program on the Disposal of Retorted Oil Shale-Paraho Oil Shale Project," prepared for US Bureau of Mines, NTIS PB-253-597 (Feb. 1975); PB-253-598 (July 1975); PB-253-599 (Dec. 1975).

Table 2. Paraho Retort Gas Properties* (dry basis)

Item	Direct Mode (vol %)	Indirect Mode (vol %)
H_2	2.5	24.8
N_2	65.7	0.7
O_2	0	0
CO	2.5	2.6
CO_2	24.2	15.1
CH_4	2.2	28.7
C_2H_4	0.7	9.0
C_2H_6	0.6	6.9
C_3	0.7	5.3
C_4	0.4	2.0
Item	(PPM)	(vol %)
H_2S	2660	3.5
NH_3	2490	1.2
High Heating Value, Btu/SCF	102	885
High Heating Value, kcal/m^3	908	7560
Retort Gas Yield, SCF/ton	6200	500
Retort Gas Yield, m^3/tonne	193	15.6

Note: from semi-works retorting of 116 liter/tonne (28 GPT) oil shale, at 97% Fischer assay yield.

*Jones, John B., "The Paraho Oil Shale Retort," 81st Nat. Mtg., A.I.Ch.E., Kansas City, Mo., April 11-14, 1976.

Table 3. Physical Properties of Paraho Direct Mode Processed Shale[a]
(Woodward-Clyde, Consultants, Denver, Colorado)

Gradation (ASTM D422)	
Maximum particle size	2 in
Clay size (0.005 mm)	2%
Silt and clay size (- No. 200 sieve)	22%
Sand size (No. 200 to No. 4 sieves)	23%
Gravel size (+ No. 4 sieve)	55%[b]
Plasticity (ASTM D423 and D424)	
Liquid limit	-
Plasticity index	nonplastic
Specific gravity (ASTM D854)	
Apparent (all sizes)	2.59[b]
Relative density[c] (ASTM D698)	
Dense (100%)	89.4 lb/ft^3[d]
Loose (0%)	71.5 lb/ft^3[d]

Compaction[c] (ASTM D698 and D1557)

	Compactive Effort	Optimum Moisture	Density (Max. at Optimum Moisture)
Low	6,200 ft-lb/ft^3	23.7%	88.0 lb/ft^3
Moderate	12,375 ft-lb/ft^3	22.0%	92.5 lb/ft^3
High	56,259 ft-lb/ft^3	22.0%	98.0 lb/ft^3

Permeability[c] (USBR Earth Manual, E-13)

	Compactive Effort	Permeability at Loading		
		50 psi	100 psi	200 psi
Low	6,200 ft-lb/ft^3	15.5 ft/yr	5.5 ft/yr	1.7 ft/yr
Moderate	12,375 ft-lb/ft^3	7.0 ft/yr	1.4 ft/yr	0.8 ft/yr
High	56,250 ft-lb/ft^3	1.1 ft/yr	0.6 ft/yr	0.08 ft/yr

(a) Sample 1-B taken from Paraho semiworks plant at Anvil Points, Colo.
(b) Average of two values
(c) Minus 1½ inch fraction
(d) Lower numbers have been reported by others on similar materials

From White River Shale Project, Draft Detailed Development Plan, p. 3.10-3, April 1976 plant and its support facilities, including a mine and processed shale disposal area, will be located on the Naval Reserves at Anvil Points (Figure 10).

As noted in Figure 10, mining will be carried out on a larger scale than the present room-and-pillar mine underground facilities. Shale will be passed through a conveyor system to a 5 acre retort plant area located on the present mine road approximately 3/4 of a mile southwest of the mine, at an elevation of approximately 7,000 feet. Retorted shale will be conveyed to the disposal area now being used for the current Paraho operations. Shale oil will be transported by rail or truck to a refinery for processing. A block flowsheet of the overall proposed operations is shown in Figure 11.

Underground Mining, Crushing

Mining. It is proposed to extend the present Paraho/USBM mine at Anvil Points to as much as 56 hectares (138 acres) underground (21.6 hectares, or 53 acres in the first 30 months of operation) in order to permit the extraction of up to 10 million tonnes (11 million tons) of raw shale. It is anticipated, however, that only 3.6 million tonnes (4 million tons) would be processed during the 30-month projected operating period of the modular plant. Run of the mine shale will average 116 liters/tonne (28 gal/ton).

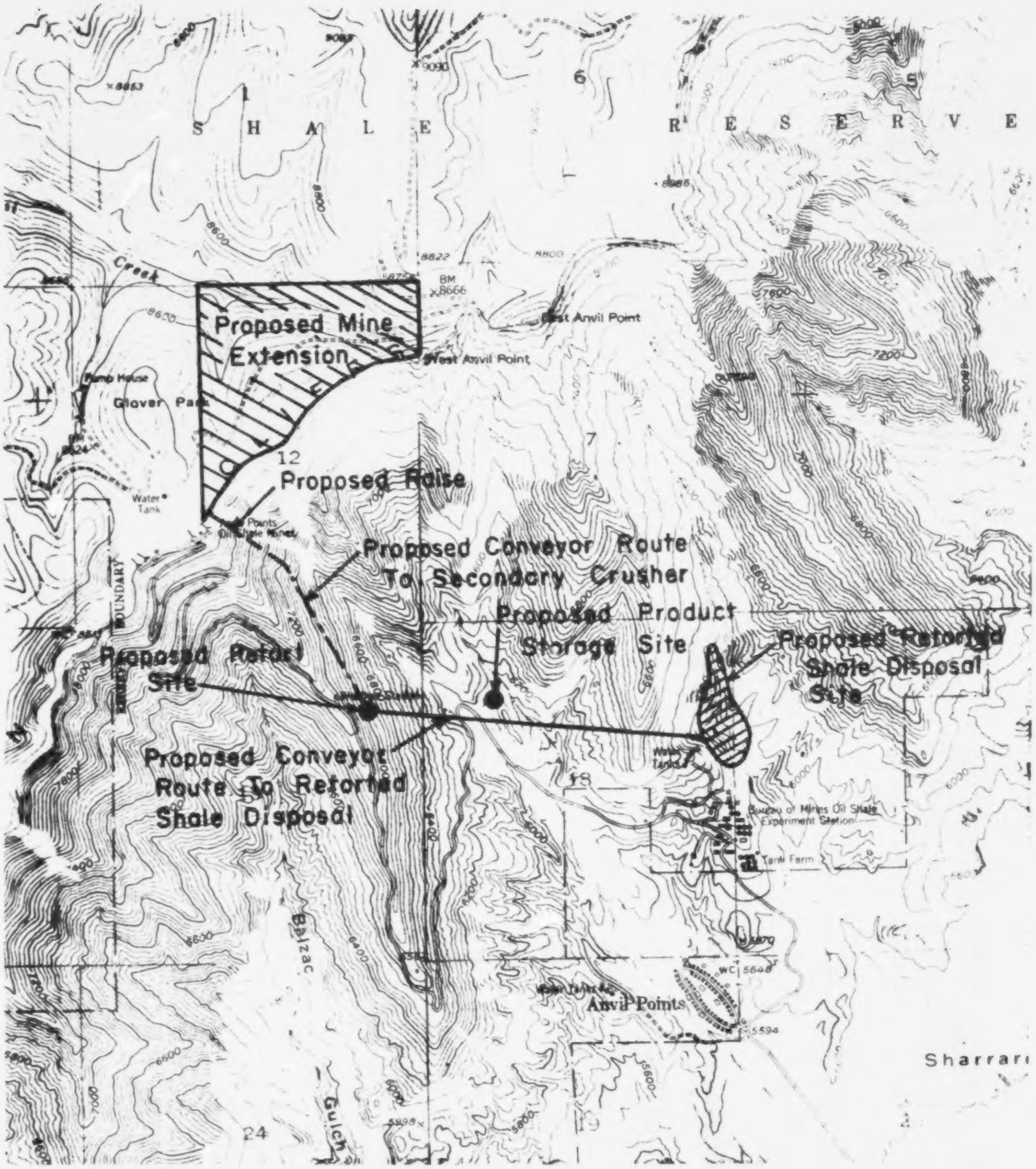
The haulage entry adit will be approximately 12.2 x 46.5 meters (40 x 150 ft) and initially 610 meters (2,000 ft) long. The underground rooms will be 18.3 meters (60 ft) wide, with 18.3 x 18.3 meters (60 ft x 60 ft) by 24.4 meter (80 ft) high pillars. Upper level drilling on a 12.2 meter (40 ft) high bench will be done with a two-drill jumbo capable of drilling 10.8 cm (4.25 in) diameter holes 9 meters (30 ft) deep in a single pass.

The primary blasting agent will be ammonium nitrate-fuel oil placed in the holes pneumatically. The blasted shale will be loaded into rear dump trucks with front end loaders.

A ventilation system similar to a coal mine system will be installed with a total air requirement of approximately 26,470 cu meters (750,000 cu ft) per minute. Mining water will come from an existing reservoir source on the plateau above the mine.

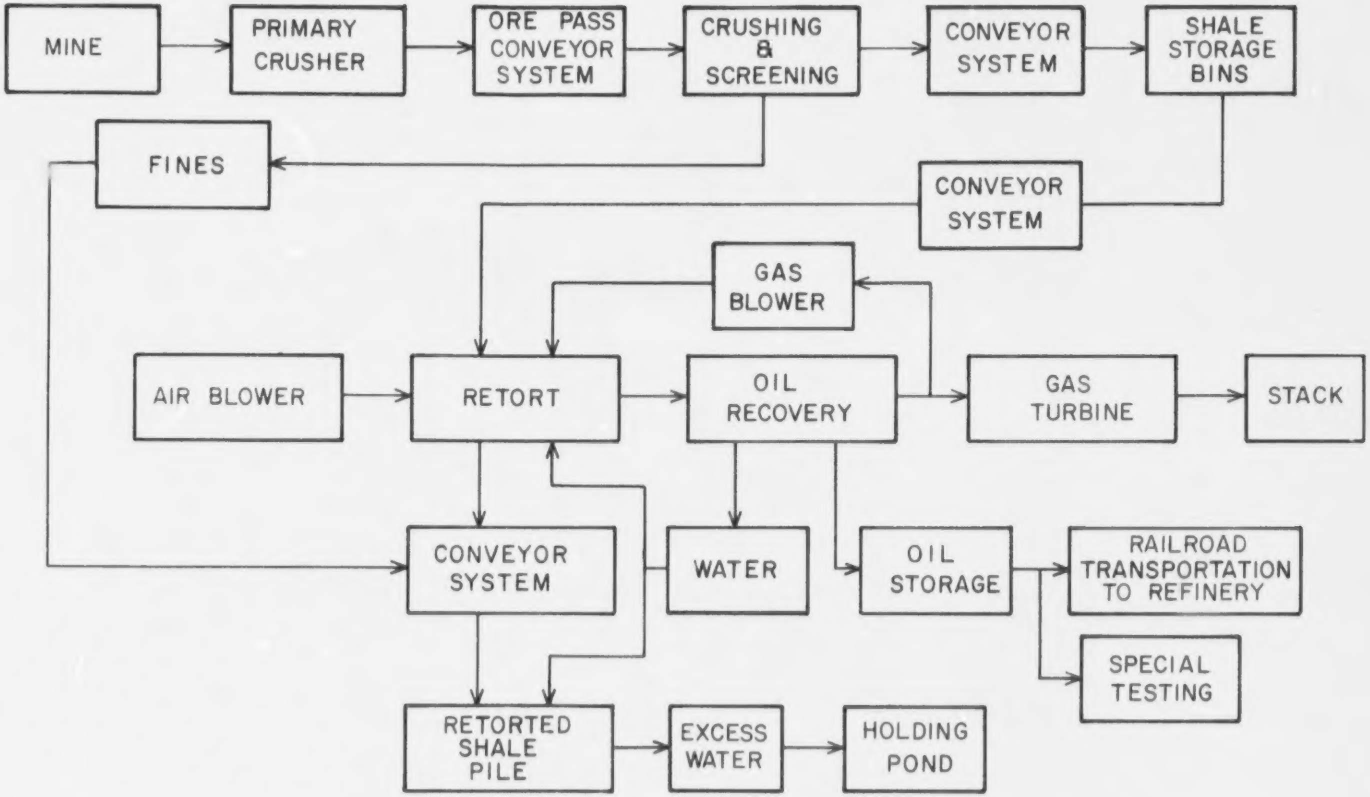
Primary Crushing. The primary crusher will be located in the mine (Figure 12) where a single or double-toothed roll crusher will reduce mine-run shale to minus 25.4 cm (10 in). A 27,200 tonne (30,000 ton) crushed shale surge pile will be maintained in the mine. After crushing, the shale will be fed into a 3 meter (10 ft) diameter orepass (Figure 10) which will deliver the shale to a conveyor adit at the retort elevation. An enclosed conveyor belt will transfer the shale to a secondary crusher at the retort site.

Secondary Crushing and Screening. The secondary crushing and screening area consists of a crushing unit, a primary screening unit, and a secondary screening unit so that various feed size ranges may be produced. Dust collection hoods will be provided at each crushing station and all screening stations. Hoods will be installed at all conveyor loading and discharge points as well as the receiving bin of the retort. The hoods will be ducted to induced draft


S H A L E R E S E R V E
Creek
Proposed Mine Extension
East Anvil Point
West Anvil Point
Pump House
Glover Pass
Water Tank
12
Proposed Raise
Proposed Conveyor Route To Secondary Crusher
Proposed Product Storage Site
Proposed Retorted Shale Disposal Site
Proposed Retort Site
Proposed Conveyor Route To Retorted Shale Disposal
BOUNDARY
Bureau of Mines Oil Shale Experiment Station
Tank Farm
Anvil Points
Balzac
Gulch
6
7
18
17
24
Sharrar

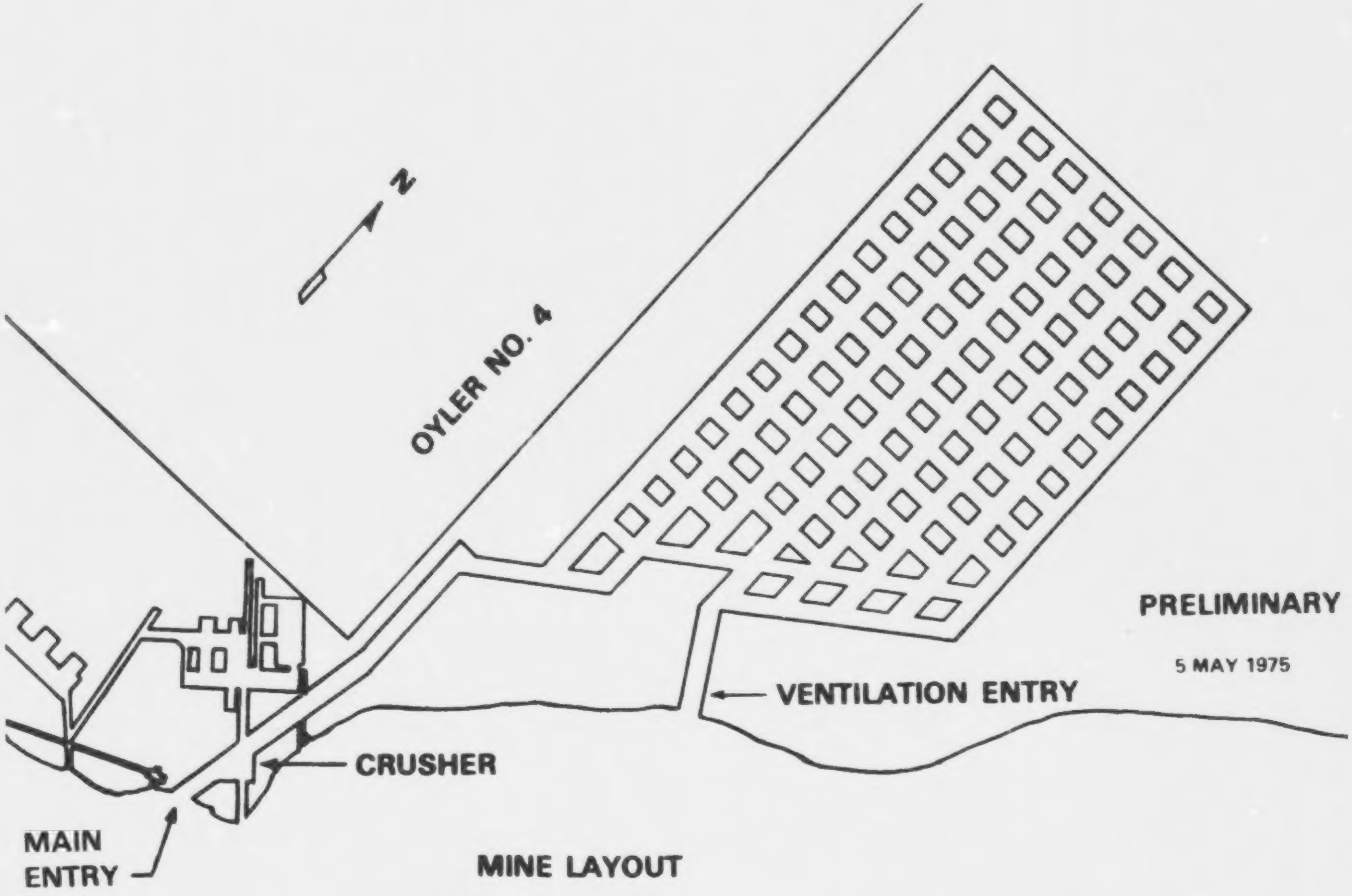
*from Draft EIA, Paraho Project, USBM, May 1975.

Figure 10. Proposed Site Additions to Anvil Points Facilities.*


MINE
PRIMARY CRUSHER
ORE PASS CONVEYOR SYSTEM
CRUSHING & SCREENING
CONVEYOR SYSTEM
SHALE STORAGE BINS
FINES
CONVEYOR SYSTEM
GAS BLOWER
AIR BLOWER
RETORT
OIL RECOVERY
GAS TURBINE
STACK
CONVEYOR SYSTEM
WATER
OIL STORAGE
RAILROAD TRANSPORTATION TO REFINERY
SPECIAL TESTING
RETORTED SHALE PILE
EXCESS WATER
HOLDING POND

*Paraho Project Brochure, Paraho Oil Shale Demonstration, Inc., 1972.

Figure 11. Block Flow Diagram of Proposed Paraho Modular Plant*


N
OYLER NO. 4
PRELIMINARY
5 MAY 1975
VENTILATION ENTRY
CRUSHER
MAIN ENTRY
MINE LAYOUT

*from Draft EIA, Paraho Project, USBM, May 1975.

Figure 12. Proposed Plan for Mine Extension.*

bag-type collectors with clean air discharge to the atmosphere. Undersized shale from the screening operation (typically 10% fines) will be used partly for road surfacing and partly for land fill.

RETORTING PLANT AUXILIARY FACILITIES

The single full-size modular Paraho retort and support facilities will be constructed on a 61 meter by 244 meter (200 ft by 800 ft) site, probably on top of the hogback (Figure 10). The vertical kiln will be 12.8 meters (42 ft) in diameter and 32 meters (104 ft) high, with a nominal capacity of up to 11,800 tonnes (13,000 tons) per day. It will be of the conventional Paraho design previously described for the Demonstration Project, and will operate in the same manner.

Minus 7.6 cm (3 in) plus 6 mm (0.25 in) feed from secondary crushing and screening will be fed to the top of the modular retort. Feed chutes will distribute the shale uniformly around the top level of the charge. Uniform rock descent throughout the cross section of the retort will be maintained by the special hydraulic grate, which also removes the retorted shale from the bottom of the retort. The shale moves downward through four zones via a mist formation zone (raw shale preheating), a retorting zone, a combustion zone, and a cooling zone (gas preheating and residue cooling). In the direct heating mode air will be fed to the retort at a rate of about 154 standard cubic meters/tonne (5,000 SCF/ton) of 116 liters/ton (28 gal/ton) raw shale throughput.

To seal the top of the retort against escaping combustion retort gases, an inert gas will be introduced into the feed chutes just above their discharge level at a pressure slightly higher than that of the gases in the retort. Retorted shale is removed from the bottom of the vessel through a battery of rotary seals. Dust collector systems will be provided for both the entry and discharge ends of the retort.

The mixture of shale oil mist-entrained in retort off gases will be collected at the top of the retort and sent through an electrostatic precipitator and associated separation equipment for oil recovery. Some 954 to 1430 cubic meters (6,000 to 9,000 barrels) of shale oil will be produced per day from 28 GPT oil shale.

The oil and some associated water would be transferred to the existing Paraho oil storage facility which has a capacity of about 2,400 cubic meters (15,000 barrels), or two days production, and subsequently transported to a local refinery for further upgrading. It is not expected that sulfur or ammonia will be recovered at Anvil Points in the operation of the modular plant.

After leaving the oil recovery system, a portion of the off gases, 500 std cubic meters/tonne (16,000 SCF/ton) of shale, will be recycled to the retort in the direct heating mode. The remainder of the gases, about 250 std cubic meters/tonne (8,000 SCF/ton) of shale, could be burned in a gas turbine in order to provide power for the gas and recycle blowers and other plant power requirements. (It may be, however, that plant power will be purchased from an outside utility source.) Alternatively, these remaining gases would be sent to a thermal oxidizer and flared.

Shale Oil Upgrading

In the original Paraho prospectus[2] proposed flow diagrams were presented for converting Paraho shale oil to (a) syncrude or (b) low sulfur distillate fuel oil. These involved conventional delayed coking, gas treating, and hydrogenation of naphtha and gas oil fractions with the recovery of ammonia, sulfur and coke. For example, in the syncrude flowsheet for a direct mode Paraho plant processing 130,600 tonnes (144,000 ton) per calendar day raw shale and producing 14,300 cubic meters (90,000 barrels) per day of syncrude, there are obtained per day, as by-products, 200 tonnes (220 tons) of ammonia, 82 tonnes (90 tons) of sulfur, and 1,180 tonnes (1,300 tons) of coke.

Yields of syncrude and by-products for a 15,900 cubic meter (100,000 barrels) per day Paraho shale oil plant have also been examined in a more recent study of energy and water requirements for commercial-scale Paraho production by McKee and Kunchal.[3] These are further discussed in the section on Energy and Water Requirements.

It should be noted that quantitative assessment of these upgrading methods and their yields must await further scale-up of the Paraho retorts. This is also true of particulate and emission control technologies for the Paraho retorting process and associated upgrading methods. These control technologies have not yet been determined since the basic retorting processes are still under development. It is expected that such pollution controls will be more fully delineated, together with the emissions and effluents involved, as further Paraho research at Anvil Points proceeds during 1977 and 1978.

RETORTED SHALE DISPOSAL

After the shale has been retorted it is discharged from the bottom of the retort to conveyors for transport to a holding bin. A dust collection system will be provided at the discharge points. Retorted shale along with some raw shale fines, will be transported by truck to the present canyon disposal area. The material will be deposited in a stable manner and moistened as necessary for dust control and for compaction.

There are approximately 2.5 kg of retort water obtained per tonne (5 lbs/ton, or 0.6 gal/ton) of raw shale throughput. (This is only about one tenth the usual gas combustion retort water yield). From a 13,000 ton/day feed rate, some 29.5 cubic meters (7,800 gallons) per day of retort water would be produced. Proposed use of this water for temperature control, dust control, and compaction of retorted shale should be carefully investigated to determine any adverse environmental impacts from included contaminants.

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[2] Paraho Project Brochure, Paraho Oil Shale Demonstration, Inc. 1972.

[3] McKee, J. M., and Kunchal, S. K., preprint, "Energy and Water Requirements for an Oil Shale Plant Based on the Paraho Process," 9th Oil Shale Symposium, Colorado School of Mines, April 29-30, 1976.

A typical analysis of such Paraho retort water from direct-mode operation is given in Table 4. A catch basin will be constructed to retain runoff water from the shale disposal area, and a culvert 1.8 meters (6 ft) in diameter by 1,280 meters (4,200 ft) long will be installed along the canyon beneath the disposal site to accommodate runoff from above, including that from a historical 100-year storm.

Table 4. Paraho Retort Water Analysis*

Cations	mg/l
Calcium	76.0
Magnesium	58.0
Sodium	290.0
Potassium	35.0
Ammonium	4910.0
Anions	
Carbonate	0.0
Bicarbonate	1500.0
Sulfate	5900.0
Chloride	5300.0
pH	7.6
C.O.D.	17,000
Nitrogen (NH_3)	3,810
Total Kjeldahl Nitrogen	4,590
Sulfide(s)	0
Solids, Total	18,100
Solids, Dissolved	17,400
Solids, Suspended	700
Total CO_3	1,300
Dissolved Organic Carbon	3,420

*From "Draft Environmental Impact Assessment for a Proposed Accelerated Paraho Oil Shale Research Project at Anvil Points, Colorado," U.S. Bureau of Mines, May 1975

It is expected that up to 3.26 million tonnes (3.6 million tons) of retorted shale and shale fines could be produced from the 3.6 million tonnes (4 million tons) of raw shale processed during the projected 30 months of operation of the modular retorting plant. Some 22 hectares (55 acres) of canyon area could be involved in their disposal at pile depths from zero up to 64 meters (210 ft). Some 14% of total canyon area would be involved. The disposal area would be compacted, contoured, and revegetated.

Paraho has carried out some unpublished studies on the disposal of partially calcined retorted shale without the addition of water. These experiments were conducted upon a fairly small area using fairly thin lifts. If an appreciable amount of time elapsed between the build-up of the various lifts, it is presumed that the retorted shale would adsorb more moisture than a full-scale operation. However, until the results of the study are available, it would be presumptious to judge the merits of such dry disposal techniques in the absence of added water.

ENERGY AND WATER REQUIREMENTS

Energy

It is expected that some 9,000 KVA net outside power requirements will be needed for mining, crushing, retorting, etc. in the commercial-module plant. The present utility corridor at Anvil Points can be used for this purpose. As mentioned above, it would be possible to supply a major portion of plant power from a gas turbine using excess retort gases as fuel. However, unless it is desirable to test a particular turbine design, this will probably not be done. Diesel fuel for mining and truck transport at the modular plant will be purchased outside.

McKee and Kunchal (see footnote 3) have computed the internal plant power requirements for a 15,900 cubic meter (100,000 barrels) per day Paraho shale oil plant processing 125 liter/tonne (30 GPT) oil shale, and operating in either direct heating or indirect heating mode. The crude shale oil is upgraded through coking and hydrotreating to either 13,800 cubic meters (87,000 barrels) per day of synfuel (direct mode) or 12,100 cubic meters (76,000 barrels) of synfuel per day (indirect mode). Also produced are 1,910 cubic meters (12,000 barrels) per day of plant diesel fuel, 2,086 tonnes (2,300 tons) per day of by-product coke, 263 tonnes (290 tons) of ammonia, and 123 tonnes (136 tons) of sulfur.

In the direct mode, the internal plant power requirements are 190 megawatts, including 49 megawatts for mining, crushing, and spent shale disposal; 72 megawatts for retorting; and 31 megawatts for pre-refining (upgrading). If the 1,184 kcal/std cu meter (133 Btu/SCF) low-Btu gas and all of the by-product coke are converted to electric power, some 583 megawatts would be generated. Therefore, some 393 megawatts (583 minus 190) of power could be exported for sale.

In the indirect mode, the authors have assumed the same 190 megawatts internal plant requirements as for the direct mode. However, the 5,875 kcal/std cu meter (660 Btu/SCF) high Btu gas produced is consumed entirely as internal plant fuel, and only the by-product coke is converted to electric power. Some 267 megawatts of power would thus be produced, of which 77 megawatts (267 minus 190) could be exported for sale.

Water

In order to supply water for the expanded mining operations, the present 2 acre-ft capacity of an existing reservoir on top of the plateau would be increased by mucking out the bottom. For the remainder of plant water requirements, primarily for personnel, the output from the current water treatment plant at the Colorado River would be increased from its present 45 acre-ft per year to 100-110 acre-ft per year, representing only 1% of the total in Table 5.

McKee and Kunchal have examined the water requirements for a full-scale Paraho oil shale plant operating with direct mode or indirect mode heating. Their data is summarized in Table 5. It is noted that the indirect heating mode consumes 40% more water than the direct heating mode, primarily for increased revegetation water needs. The greatest single need for water, in either mode, is for plant cooling tower makeup.

Table 5. Water Requirements for a 59,000 m^3/Day (100,000 BPD) Paraho Shale Oil Plant*
Basis: 125 liters/tonne (30 gal/ton) oil shale

	Water Requirements (Acre-ft/yr)**	
	Direct Mode	Indirect Mode
Plant Cooling Tower Makeup	6,530	6,530
Mining and Crushing	1,260	1,260
Revegetation	2,130	6,110
Misc. Evaporation from Dust Control	1,450	720
Total Water Consumed	11,370	14,620
Retort Water Produced	1,370	620
Net Raw Water Makeup	10,000	14,000

*Adapted from McKee, J. M., Kunchal, E. K., "Energy and Water Requirements for an Oil Shale Plant Based on the Paraho Process," 9th Oil Shale Symposium, Colorado School of Mines, April 29, 1976.

**One acre-foot equals 1233.5 cubic meters.

TOSCO II OIL SHALE PROCESS

Charles H. Prien

TOSCO II is a process developed by The Oil Shale Corporation (TOSCO). It is the only U.S. surface retorting method which uses solid-to-solid heat transfer between hot ceramic pellets and crushed oil shale, in a horizontal, rotating retort, for shale oil production.

BACKGROUND

Initial development work (1955-1966) was conducted under TOSCO sponsorship by the University of Denver Research Institute in a 21.6 metric ton/day (24 ton/day) pilot plant. In 1964 a joint venture of Standard Oil Company of Ohio, Cleveland Cliffs Iron Company and TOSCO was formed. A 900 metric ton/day (1,000 ton/day) semi-works plant was constructed on the 3441 hectares (8,500 acres) Dow property on upper Parachute Creek near Grand Valley, Colorado (Figure 13)*. When Atlantic Richfield joined the venture in 1969, the venture name was changed to Colony Development Operation. (Later, Ashland Oil Company and Shell Oil Company replaced Sohio and Cliffs).

The semi-works plant and associated pilot room-and-pillar mine were operated until 1972. Over one million metric tons of shale were mined during this period. Some 31,700 cubic meters (200,000 bbls) of oil were produced from the 260,000 metric tons (290,000 tons) subsequently retorted.

A full-scale 59,800 metric tons/stream day (66,000 tons/stream day) commercial plant which would produce 7,400 cubic meters/day (47,000 bbl/day) of low sulfur fuel oil and 680 cubic meters/day (4,300 bbl/day) of LPG has been designed. The plant would be located on the Dow West property of the Middle Fork of Parachute Creek, with spent shale disposal in nearby Davis Gulch (Figure 14). Plans for commercialization have been dormant since 1974 pending initiation of a federally-sponsored synfuels commercialization program.

The TOSCO/Colony group probably conducted a more extensive environmental assessment of its proposed plant than any other shale developer. A 20-volume

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*All Figures in this Overview Report are reproduced from either the Colony Environmental Impact Analysis or the BLM Environmental Impact Statement cited elsewhere as references, q.v.

**An Environmental Impact Analysis for a Shale Oil Complex at Parachute Creek Colo., Colony Development Operation, 1974.

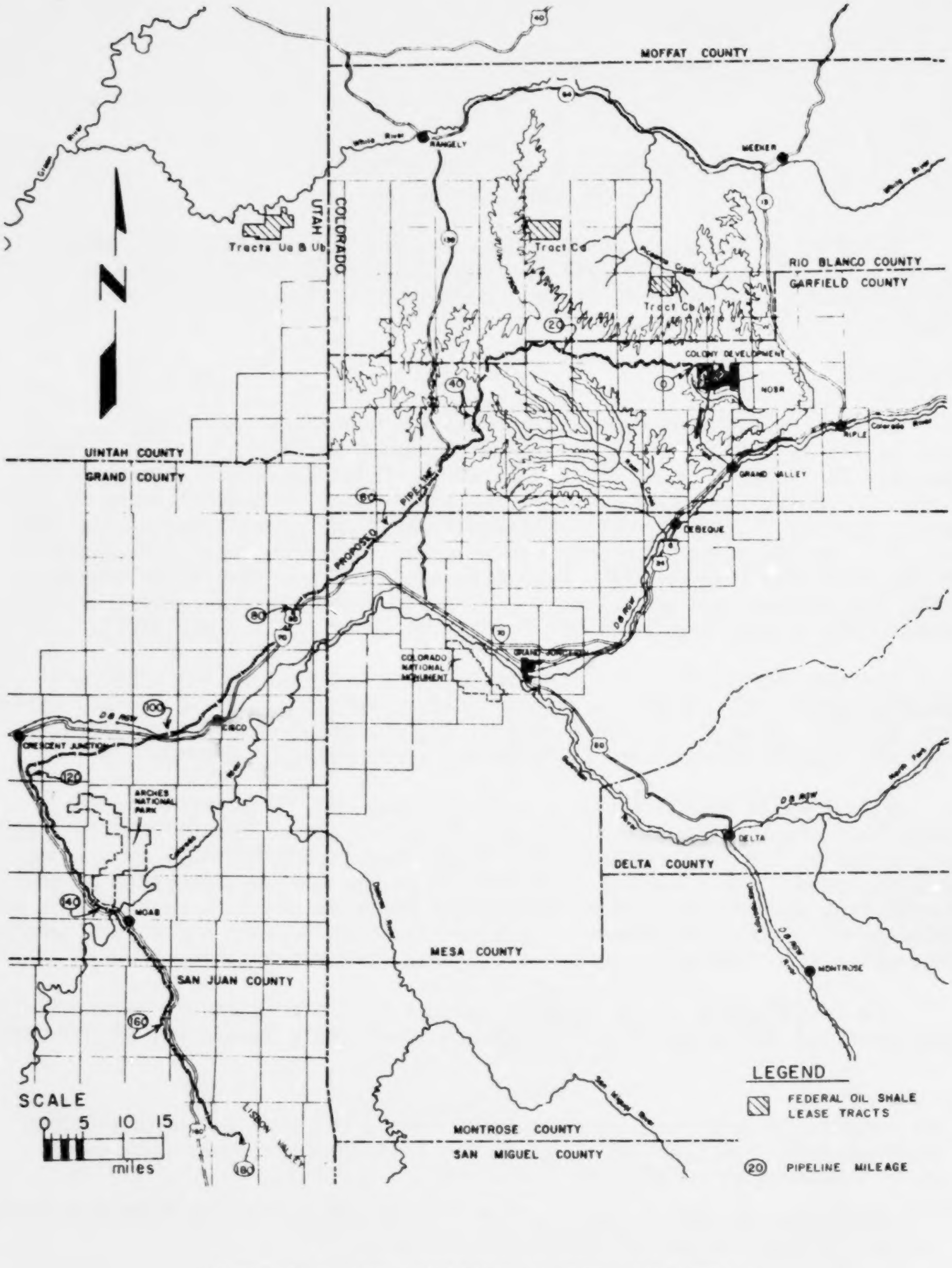
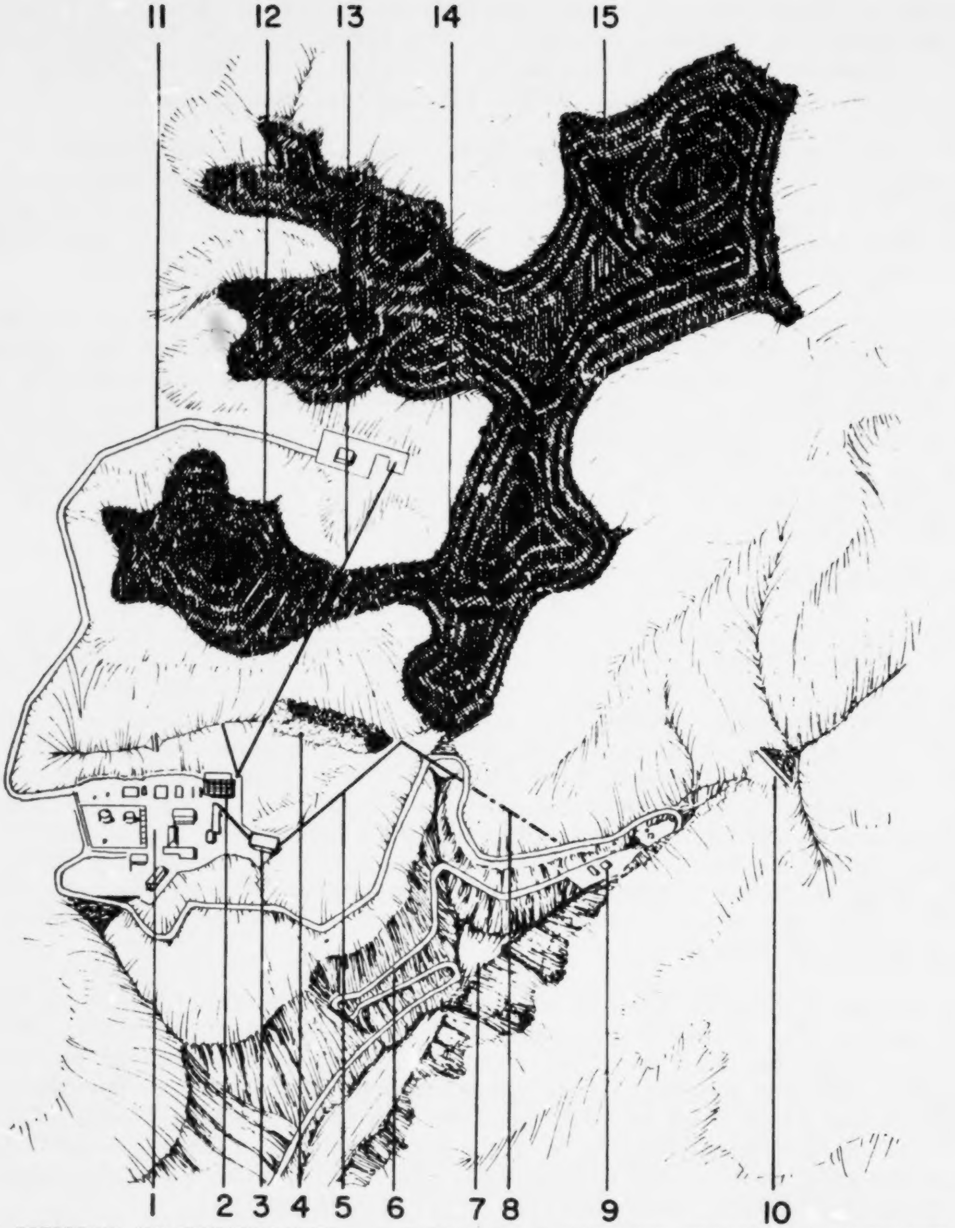

MOFFAT COUNTY
White River
RANGELY
MEEKER
Green River
Tracts Ua & Ub
UTAH
COLORADO
Tract Ca
Tract Cb
RIO BLANCO COUNTY
GARFIELD COUNTY
N
COLONY DEVELOPMENT
NOSR
RIFLE
Colorado River
UINTAH COUNTY
GRAND COUNTY
GRAND VALLEY
PROPOSED PIPELINE
DEBEQUE
COLORADO NATIONAL MONUMENT
GRAND JUNCTION
CISCO
CRESCENT JUNCTION
ARCHES NATIONAL PARK
DELTA
DELTA COUNTY
MOAB
MESA COUNTY
SAN JUAN COUNTY
MONTROSE
LEGEND
FEDERAL OIL SHALE LEASE TRACTS
PIPELINE MILEAGE
SCALE
0 5 10 15
miles
MONTROSE COUNTY
SAN MIGUEL COUNTY
LISBON VALLEY
20
40
60
80
100
120
140
160
180

Figure 13. Area Setting of Proposed Action



1 RETORTING AND UPGRADING UNITS 2 PYROLYSIS 3 SECONDARY CRUSHER 4 COARSE ORE STORAGE 5 COARSE ORE CONVEYOR FROM TUNNEL TO FINAL CRUSHING 6 PLANT MINE BENCH ACCESS ROAD 7 MIDDLE FORK OF PARACHUTE CREEK 8 COARSE ORE CONVEYOR THROUGH TUNNEL FROM MINE BENCH 9 MINE BENCH AND PRIMARY CRUSHING 10 MIDDLE FORK DAM 11 ACCESS ROAD TO PROCESSED SHALE DISPOSAL 12 PROCESSED SHALE DISPOSAL IN DAVIS GULCH SIDE GULLY 13 PROCESSED SHALE CONVEYOR 14 DAVIS GULCH DAM 15 DAVIS GULCH

Figure 14. Shale Oil Complex - Composite Aerial View

Environmental Impact Analysis was published by Colony in 1974*. A formal Draft Environmental Impact Statement, by the Bureau of Land Management was issued in December 1975**. Hearings on the latter occurred in January 1976. As of late 1976, final approval of the EIS had not been granted.

The above environmental studies have resulted in a more detailed disclosure of the TOSCO II process and its proposed control technologies, than any other U.S. process to date. The technical details available from these sources have been utilized in this Overview Report together with supplemental information kindly furnished through contacts with TOSCO personnel.

The technical description of the TOSCO II Process in the sections which follow is based upon the proposed full-scale 66,000 tons/stream day commercial plant complex (Figure 14). This includes an underground mine eventually extending over 4,000 acres, a retorting and upgrading facility, a processed shale disposal area, and two water reservoirs. A 40 cm (16 inch) diameter, 310 km (194 mile) long product fuel oil pipeline (Figure 13)* is proposed to Lisbon Valley Station, Utah, for eventual connection to a major interstate pipeline at Aneth, Utah.

UNDERGROUND MINING, CRUSHING

The TOSCO II commercial plant will include conventional underground room-and-pillar mine (Figure 15), with access by means of seven 9 meter by 9 meter (30 ft by 30 ft) adits from Middle Fork Canyon. The mine will produce 55,000 metric tons/day (61,000 tons/day) of 145 liters/metric ton (35 gallon/ton) oil shale, from an 18 meter (60 ft) seam of the upper Mahogany Zone. Some six 15 meters high by 9 meters wide (50 ft by 30 ft) ventilation openings, without scrubbers, will be provided for air circulation. The diesel equipment used underground will utilize mounted catalytic scrubbers. Total hourly emissions from the mine ventilation system are estimated to average 20 kg particulates (higher during blasting), 22 kg hydrocarbons, 113 kg NO_x, and 200 kg CO. Dust concentrations are estimated not to exceed 4,000 micrograms/cubic meter (except during blasting).

Primary crushing of the run-of-mine shale will be carried out at the mine portal bench. The coarse ore product will be transported by totally enclosed incline conveyor to the final crusher at the plant site on top of the plateau, 275 meters (900 ft) above the mine portal bench. The product from the final crusher is the minus 1.25 cm (0.5 in) feed for the retorting plant. Particulate emissions are estimated to be 3.6 kg/hr from the primary crusher, 5.4 kg/hr from transfer points, 16.8 kg/hr from the final crusher, and 2.1 kg/hr from final fine ore (retort feed) storage (or 27.9 kg/hr total).

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*An Environmental Impact Analysis for a Shale Oil Complex at Parachute Creek, Colo., Colony Development Operation, 1974.

**Proposed Development of Oil Shale Resources by Colony Development Operation in Colorado, Draft Environmental Impact Statement, Bureau of Land Management, Dept. of Interior, December 1975.

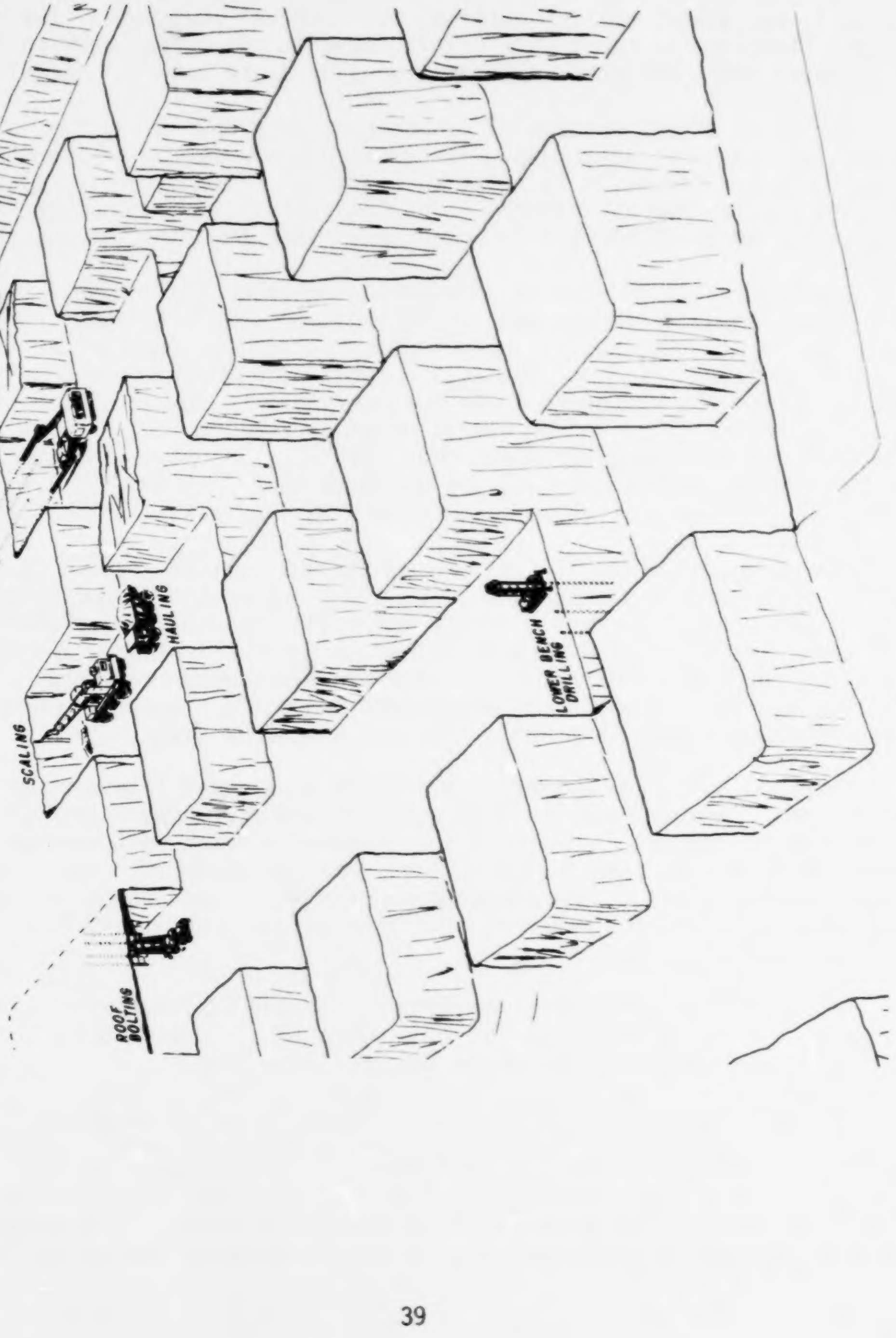

LOADING (MUCKING)
UPPER BENCH DRILLING
HAULING
SCALING
ROOF BOLTING
LOWER BENCH DRILLING

Figure 15. Room-and-Pillar Mining Concept

RETORTING AND OIL RECOVERY UNIT

Unlike some U.S. oil shale processes, the TOSCO II/Colony commercial plant is designed not only to produce shale oil, but also to upgrade it on-site to produce synthetic crude oil and LPG, with ammonia, sulfur, and coke as by-products. In addition, a treated fuel gas, a C_4 liquid stream, fuel oil, and diesel oil are obtained for internal plant use. The overall process flowsheet to carry this out is shown in simplified form in Figure 16. It is noted that processed shale is the major waste material for disposal.

The heart of the processing sequence is the TOSCO II pyrolysis (retorting) unit and associated oil recovery equipment. The flowsheet for a single unit (or "train"), is shown in Figure 17. The commercial plant will be composed of six such retorting/oil recovery units, each with a design capacity of up to 10,000 metric tons/day (11,000 tons/day) of raw shale.

The minus 1.25 cm (0.5 in) raw shale from the final crusher is first fed to a dilute phase fluidized bed, where it is preheated to about 260°C (500°F) with flue gases from the ball heater (see Figure 17). The residual hydrocarbons in the flue gases are simultaneously burned. The cooled flue gases are separated from the preheated shale, wet-scrubbed to remove particulates, which are disposed as a sludge (780 metric tons/day - 860 tons/day per train), and vented to the atmosphere at about 55°C (130°F). The hourly gaseous emissions from each of the six trains are estimated to be 3.7 kg SO_2, 99.5 kg NO_x, 3.3 kg CO, 20.4 kg total hydrocarbons, and 18.4 kg particulate matter.

The preheated shale is fed to a horizontal rotating retort (pyrolysis drum), together with approximately 1.5 times its weight in hot ceramic balls from a ball-heater in order to raise the shale to pyrolysis temperature (900°F) and convert its contained organic matter to shale oil vapor. The shale vapors are withdrawn and fed to a fractionator for hydrocarbon recovery. The mixture of balls and denuded shale are discharged through a trommel, in order to separate the emerging warm balls from the processed shale.

The warm balls are purged of dust with flue gases from a steam preheater, and the dust removed from the flue gases by wet scrubbing. Each of the six 10,000 metric ton/day "trains" of the commercial plant will produce some 59 metric tons/day (65 tons/day) of sludge dust for disposal. The scrubbed flue gases are discharged to the atmosphere. The hourly emissions in the flue gases from each train are estimated to be 7.2 kg SO_2, 8.6 kg NO_x, 0.2 kg CO, and 16.3 kg particulate matter.

The dust-free warm balls are returned to the ball heater via the ball elevator. In the ball-heater they are reheated to about 700°C (1300°F), using in-plant fuel, and recirculated to the pyrolysis drum.

The hot processed shale (denuded of oil) is cooled to about 150°C (300°F) in a rotating drum cooler and moisturized to about 14% water content with 6,000 liters/minute (1,500 gal/min) per train of NH_3, H_2S, and CO_2-free water from the plant's foul water stripper unit. The wetted shale, at below 93°C (200°F) is transported to the Davis Gulch disposal site. The steam-dust mixture produced in the moisturizer is wet-scrubbed to remove dust and

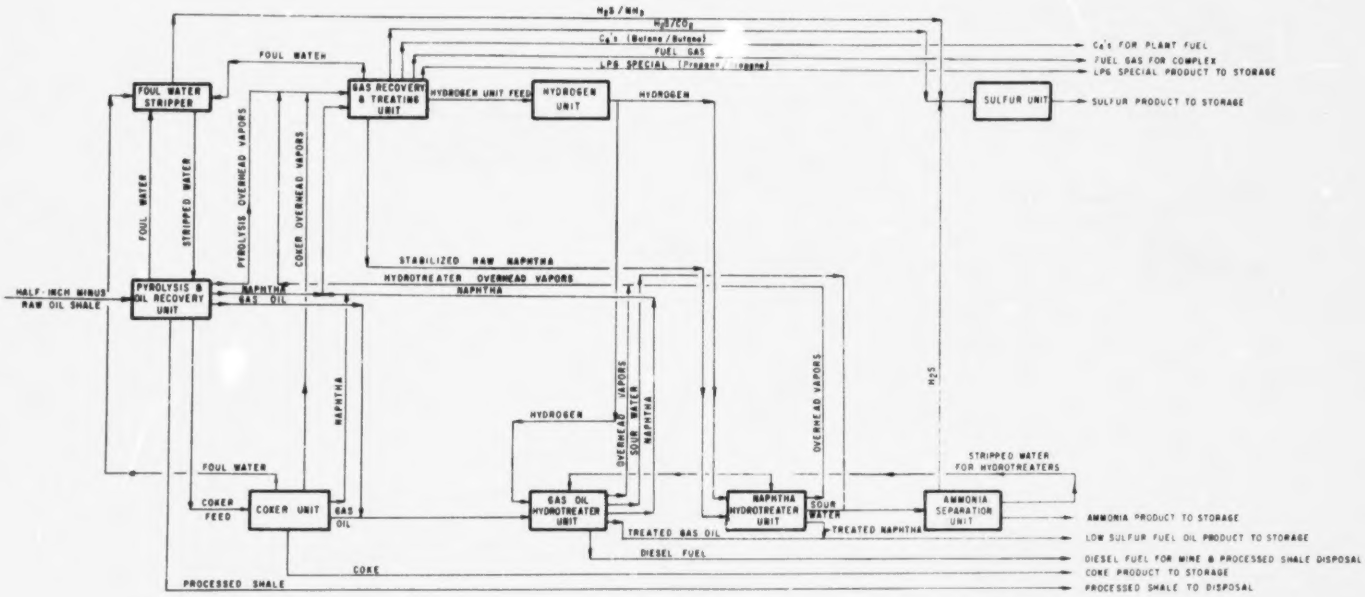
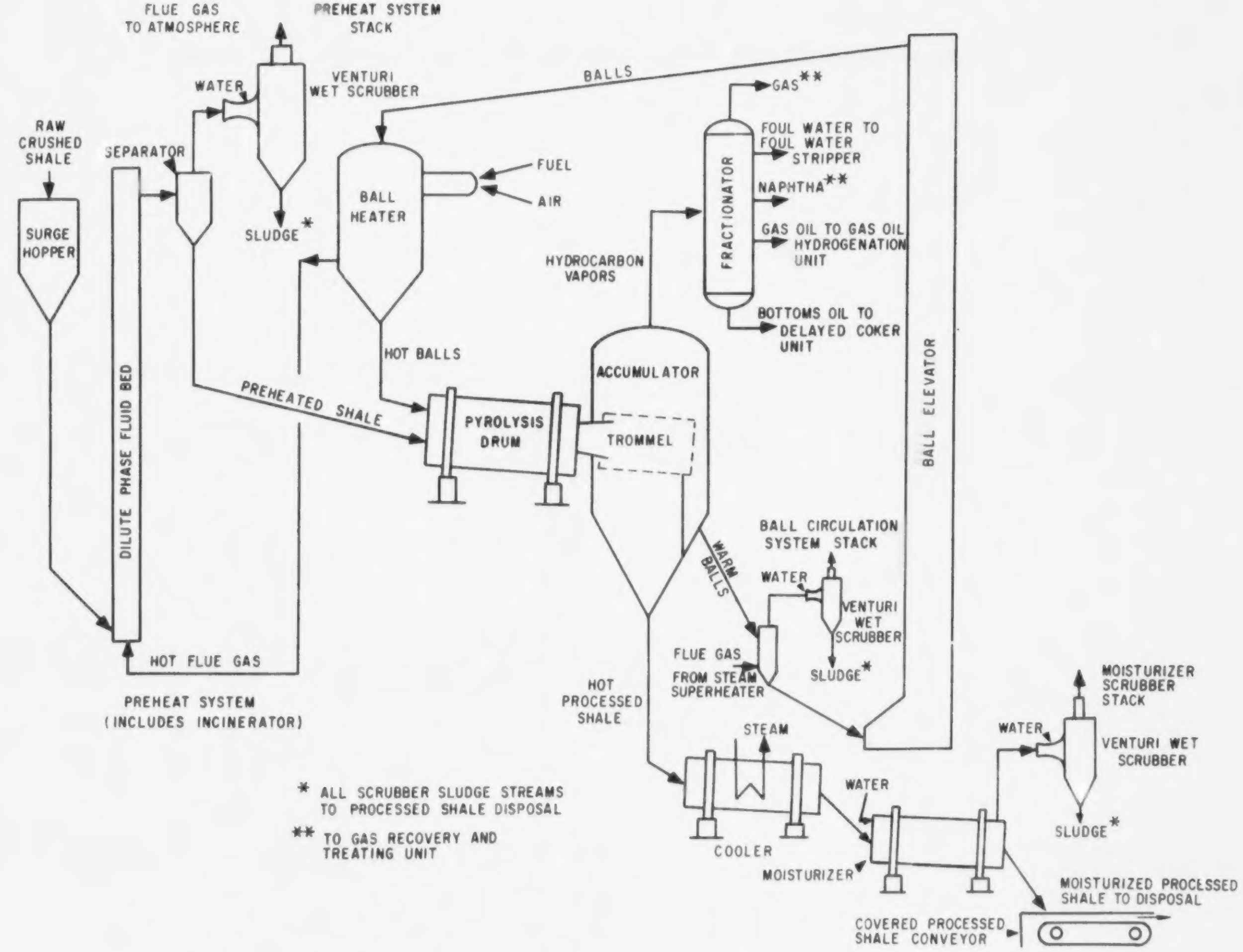

HALF-INCH MINUS RAW OIL SHALE
PYROLYSIS & OIL RECOVERY UNIT
FOUL WATER STRIPPER
FOUL WATER
STRIPPED WATER
PYROLYSIS OVERHEAD VAPORS
COKER OVERHEAD VAPORS
GAS RECOVERY & TREATING UNIT
HYDROGEN UNIT FEED
HYDROGEN UNIT
HYDROGEN
H_2S/NH_3
H_2S/CO_2
C_4's (Butane / Butene)
FUEL GAS
LPG SPECIAL (Propane / Propene)
C_4's FOR PLANT FUEL
FUEL GAS FOR COMPLEX
LPG SPECIAL PRODUCT TO STORAGE
SULFUR UNIT
SULFUR PRODUCT TO STORAGE
STABILIZED RAW NAPHTHA
HYDROTREATER OVERHEAD VAPORS
NAPHTHA
GAS OIL
COKER FEED
COKER UNIT
COKE
PROCESSED SHALE
GAS OIL HYDROTREATER UNIT
OVERHEAD VAPORS
SOUR WATER
TREATED GAS OIL
DIESEL FUEL
NAPHTHA HYDROTREATER UNIT
TREATED NAPHTHA
H_2S
AMMONIA SEPARATION UNIT
STRIPPED WATER FOR HYDROTREATERS
AMMONIA PRODUCT TO STORAGE
LOW SULFUR FUEL OIL PRODUCT TO STORAGE
DIESEL FUEL FOR MINE & PROCESSED SHALE DISPOSAL
COKE PRODUCT TO STORAGE
PROCESSED SHALE TO DISPOSAL

Figure 16. Block Flow Diagram Retorting and Upgrading Units


FLUE GAS TO ATMOSPHERE
PREHEAT SYSTEM STACK
WATER
VENTURI WET SCRUBBER
BALLS
GAS**
RAW CRUSHED SHALE
SEPARATOR
FOUL WATER TO FOUL WATER STRIPPER
FUEL
AIR
BALL HEATER
NAPHTHA**
SURGE HOPPER
SLUDGE*
FRACTIONATOR
GAS OIL TO GAS OIL HYDROGENATION UNIT
HYDROCARBON VAPORS
BOTTOMS OIL TO DELAYED COKER UNIT
HOT BALLS
ACCUMULATOR
DILUTE PHASE FLUID BED
PREHEATED SHALE
PYROLYSIS DRUM
TROMMEL
BALL ELEVATOR
BALL CIRCULATION SYSTEM STACK
WARM BALLS
WATER
VENTURI WET SCRUBBER
FLUE GAS FROM STEAM SUPERHEATER
SLUDGE*
HOT FLUE GAS
PREHEAT SYSTEM (INCLUDES INCINERATOR)
HOT PROCESSED SHALE
MOISTURIZER SCRUBBER STACK
STEAM
WATER
VENTURI WET SCRUBBER
WATER
COOLER
SLUDGE*
MOISTURIZER
MOISTURIZED PROCESSED SHALE TO DISPOSAL
COVERED PROCESSED SHALE CONVEYOR

* ALL SCRUBBER SLUDGE STREAMS TO PROCESSED SHALE DISPOSAL

** TO GAS RECOVERY AND TREATING UNIT

Figure 17. Pyrolysis and Oil Recovery Unit TOSCO II Process

discharged to the atmosphere. Each train discharges 18.4 kg/hr of particulate matter to the atmosphere, and disposes of 39 metric tons/day (43 tons/day) of dust as wet sludge.

The shale oil hydrocarbon vapors from the pyrolysis drum are separated into water, gas, naphtha, gas oil, and bottom oil in a fractionator. The water is sent to the foul water stripper, the gas and naphtha to the gas recovery and treating unit, the gas oil to a hydrogenation unit, and the bottoms oil to the delayed coking unit. The upgrading plant is discussed more fully below.

UPGRADING UNITS

As shown in Figure 16, the upgrading section of the commercial plant consists of the following units: gas recovery and treating, hydrogen production, gas oil hydrogenation, naphtha hydrogenation, ammonia separation, sulfur recovery, delayed coking and foul water stripping. These upgrading units process the individual fractionator product streams from all six pyrolysis and oil recovery trains.

Gas Recovery and Treating Unit

The gas and raw naphtha from the six shale oil fractionators, delayed coker, and the naphtha and gas oil hydrotreaters are all fed to the Gas Recovery and Treating Unit (Figure 18), where they are separated into stabilized naphtha, LPG, butanes, and fuel gas. The stabilized naphtha is sent to the naphtha hydrotreater. The butanes are used as plant fuel, as is part of the treated fuel gas. The remainder of the fuel gas is fed to the hydrogen plant. The LPG is sent to storage for sale. Acid gas from the amine treaters is sent to the sulfur unit. Since all streams exiting from the Gas Recovery and Treating Unit are sent to other units, there are no emissions to the atmosphere or byproduct liquid effluents.

Hydrogen Unit

Hydrogen is needed for the naphtha and gas oil hydrotreaters to remove nitrogen and sulfur and saturate olefins. This hydrogen is produced from a portion of the fuel gas from the gas recovery and treating unit using a conventional steam-reforming process (Figure 19) with the usual nickel catalyst plus iron/chromium oxide and copper/zinc shift catalysts. Prior to reforming, the gas is desulfurized. The normal hourly emissions to the atmosphere from the reformers are estimated to be 12.4 kg SO_2, 37.3 kg NO_x, 3.6 kg CO, 5.2 kg solid particulates, and 0.72 kg total hydrocarbons. In addition, there will be emitted 98 metric tons/hr (108 tons/hr) of CO_2 from the carbon dioxide scrubbers. Spent catalysts will be sent off-site for reclamation or disposed of in the processed shale pile.

Gas Oil Hydrogenation Unit

The feeds to this unit (Figure 20) are the gas oil streams from the oil recovery fractionators and the delayed coker unit. These are hydrogenated to reduce sulfur and nitrogen and saturate olefins. Arsenic is also removed

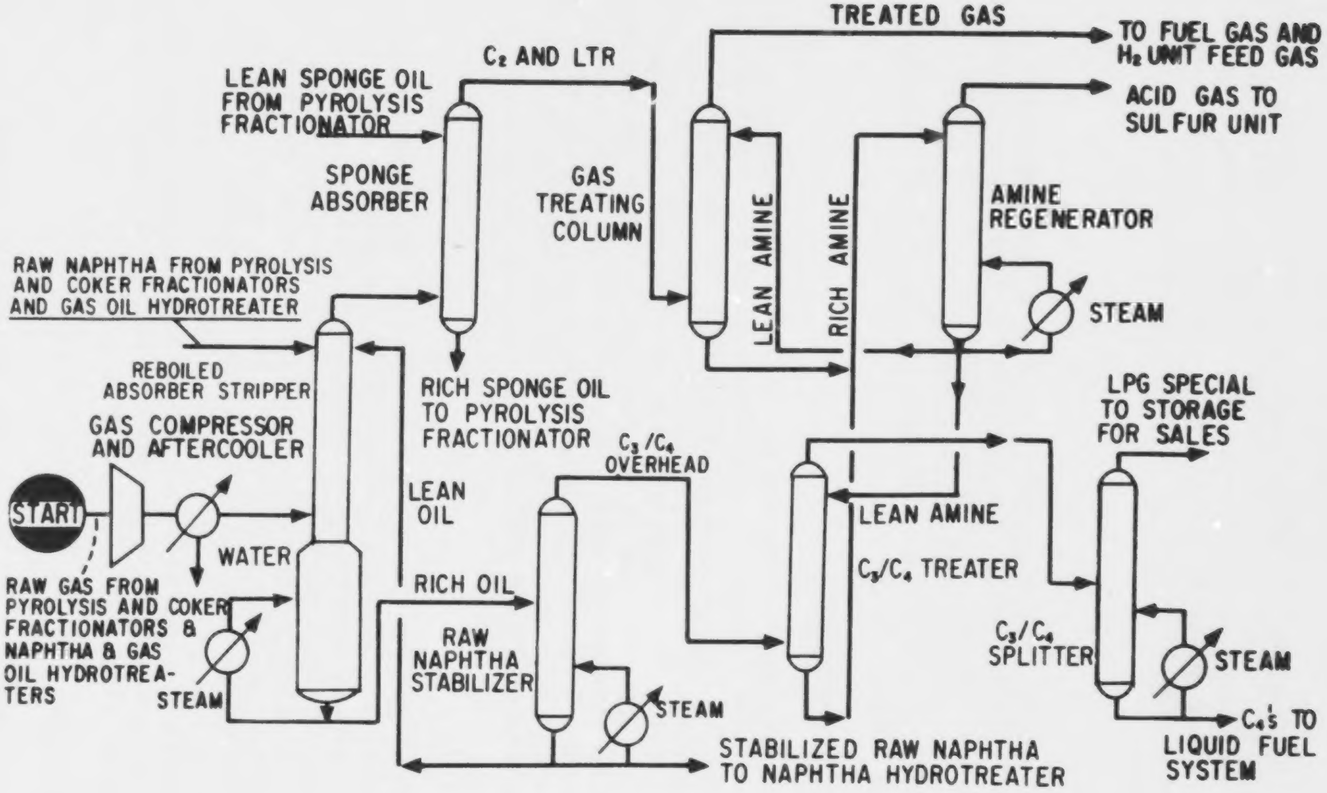

TREATED GAS
TO FUEL GAS AND H_2 UNIT FEED GAS
C_2 AND LTR
LEAN SPONGE OIL FROM PYROLYSIS FRACTIONATOR
ACID GAS TO SULFUR UNIT
SPONGE ABSORBER
GAS TREATING COLUMN
LEAN AMINE
RICH AMINE
AMINE REGENERATOR
STEAM
RAW NAPHTHA FROM PYROLYSIS AND COKER FRACTIONATORS AND GAS OIL HYDROTREATER
REBOILED ABSORBER STRIPPER
RICH SPONGE OIL TO PYROLYSIS FRACTIONATOR
LPG SPECIAL TO STORAGE FOR SALES
GAS COMPRESSOR AND AFTERCOOLER
C_3/C_4 OVERHEAD
START
LEAN OIL
LEAN AMINE
WATER
C_3/C_4 TREATER
RAW GAS FROM PYROLYSIS AND COKER FRACTIONATORS & NAPHTHA & GAS OIL HYDROTREATERS
RICH OIL
RAW NAPHTHA STABILIZER
C_3/C_4 SPLITTER
STEAM
STEAM
STEAM
C_4's TO LIQUID FUEL SYSTEM
STABILIZED RAW NAPHTHA TO NAPHTHA HYDROTREATER

Figure 18. Gas Recovery and Treating Unit

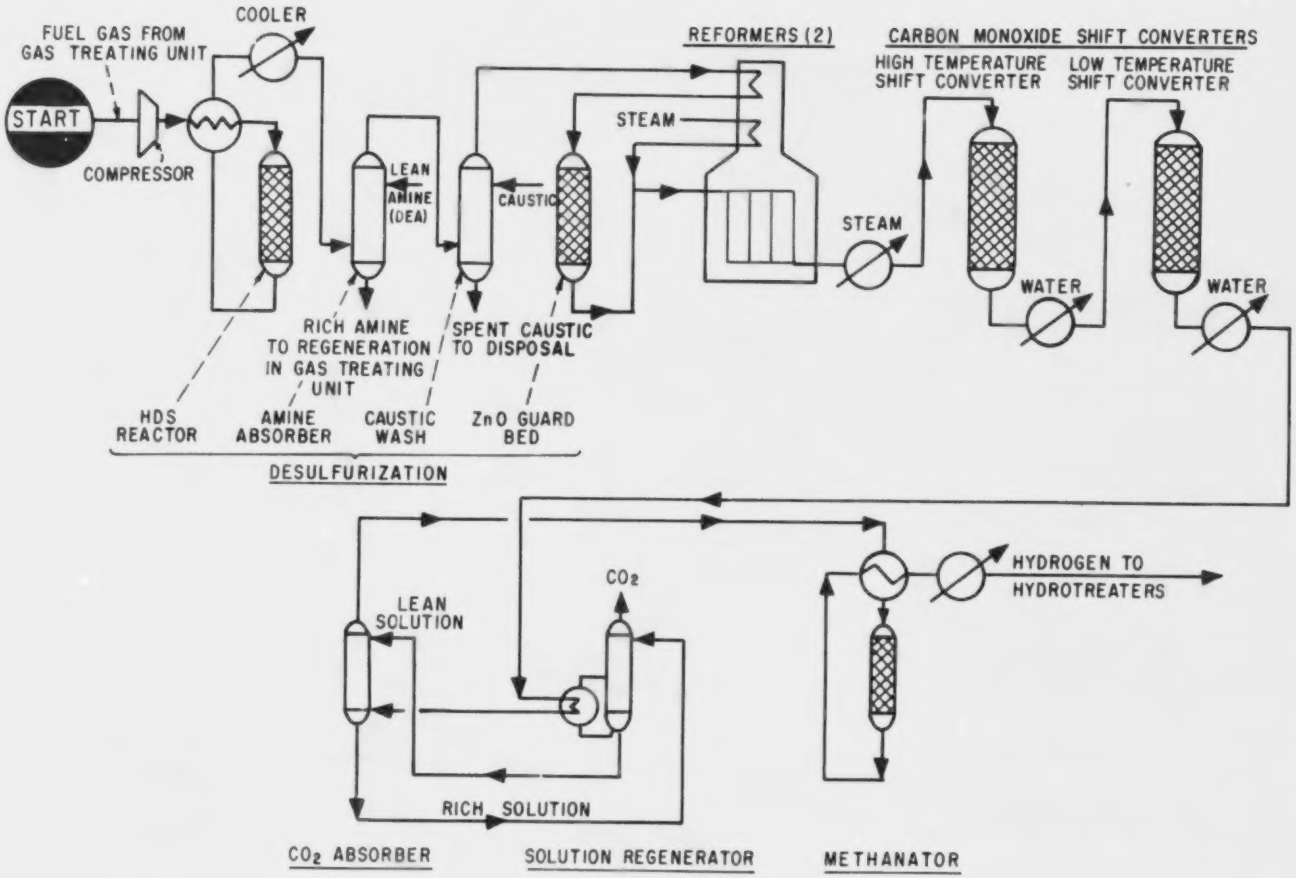

FUEL GAS FROM GAS TREATING UNIT
START
COMPRESSOR
COOLER
LEAN AMINE (DEA)
CAUSTIC
STEAM
REFORMERS (2)
CARBON MONOXIDE SHIFT CONVERTERS
HIGH TEMPERATURE SHIFT CONVERTER
LOW TEMPERATURE SHIFT CONVERTER
STEAM
WATER
WATER
RICH AMINE TO REGENERATION IN GAS TREATING UNIT
SPENT CAUSTIC TO DISPOSAL
HDS REACTOR
AMINE ABSORBER
CAUSTIC WASH
ZnO GUARD BED
DESULFURIZATION
HYDROGEN TO HYDROTREATERS
CO2
LEAN SOLUTION
RICH SOLUTION
CO2 ABSORBER
SOLUTION REGENERATOR
METHANATOR

Figure 19. Hydrogen Unit, Steam Reforming Process

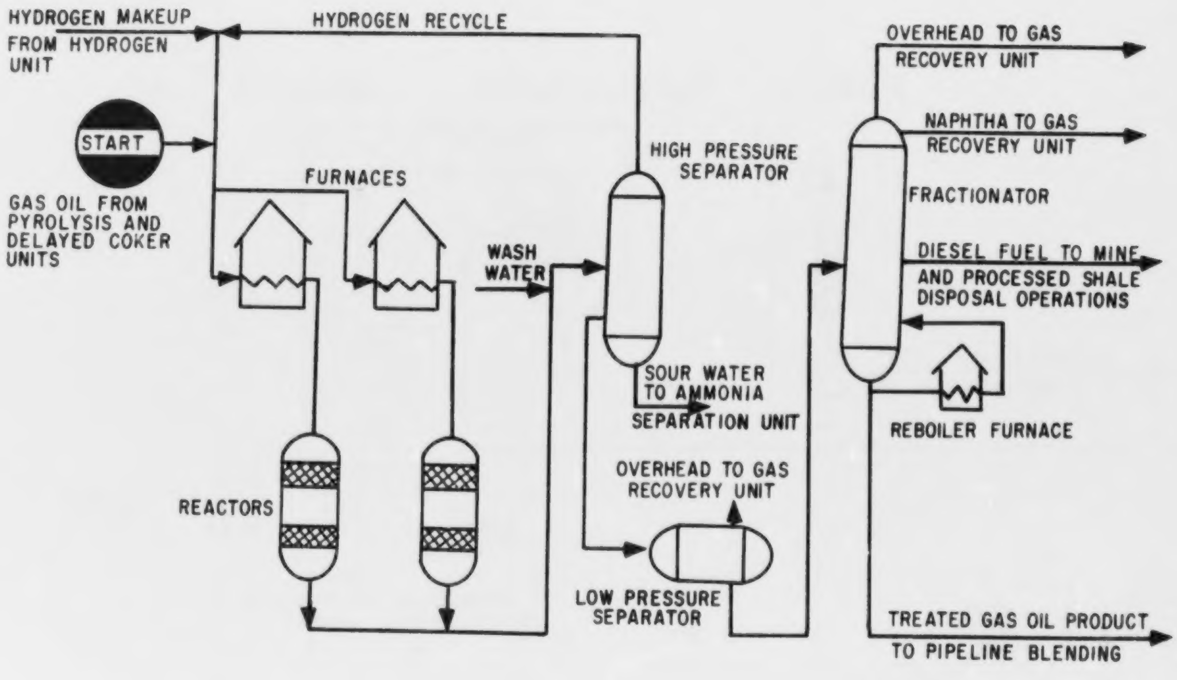

HYDROGEN MAKEUP
FROM HYDROGEN UNIT
HYDROGEN RECYCLE
START
GAS OIL FROM PYROLYSIS AND DELAYED COKER UNITS
FURNACES
REACTORS
WASH WATER
HIGH PRESSURE SEPARATOR
SOUR WATER TO AMMONIA SEPARATION UNIT
OVERHEAD TO GAS RECOVERY UNIT
LOW PRESSURE SEPARATOR
OVERHEAD TO GAS
RECOVERY UNIT
NAPHTHA TO GAS
RECOVERY UNIT
FRACTIONATOR
DIESEL FUEL TO MINE
AND PROCESSED SHALE DISPOSAL OPERATIONS
REBOILER FURNACE
TREATED GAS OIL PRODUCT
TO PIPELINE BLENDING

Figure 20. Gas Oil Hydrogenation Unit

using a proprietary catalyst. The major products are a low sulfur and nitrogen treated gas oil for sale, and diesel fuel for in-plant use (mine, and processed shale disposal operations). The gas and naphtha from the fractionator are sent to the gas recovery unit. Sour water from the washing operations, containing NH_3 and H_2S, is fed to the ammonia recovery unit, where H_2S is removed and sent to sulfur recovery. The hourly atmospheric emissions from the gas oil hydrogenation unit reboiler furnace are 1.7 kg SO_2, 5.1 kg NO_x, 0.65 kg CO, 0.7 kg particulate matter, and 90 grams total hydrocarbons. In addition, some 240 kg (531 lbs) per day of arsenic in solid form will be discarded on the processed shale disposal pile.

Naphtha Hydrogenation Unit

The stabilized naphtha stream from the Gas Recovery and Treating Unit is catalytically hydrogenated to remove sulfur and nitrogen and saturate the olefins present, in the Naphtha Hydrogenation Unit (Figure 21). Prior to hydrogenation arsenic is removed over a proprietary catalyst. Some 27 kg (59 lbs) per day of arsenic are produced, for discard on the spent shale pile.

The arsenic-free feed is hydrogenated in the presence of an HDN (hydrodenitrogenation) catalyst, and the reactor effluent is washed with stripped water from the ammonia separation unit, in order to remove H_2S and NH_3. The resulting sour water is sent to the Ammonia Separation Unit for purification.

The resulting H_2S and NH_3-free mixed hydrocarbon stream is sent to an absorber to remove heavier hydrocarbons. The absorber's overhead gases are returned to the Gas Recovery and Treating Unit. The treated naphtha product is blended with the previously mentioned treated gas oil product to form the low sulfur fuel oil for sale.

The hourly emissions from the Naphtha Hydrogenation Unit are 0.18 kg SO_2, 0.6 kg NO_x, 0.9 kg CO, 0.047 kg total hydrocarbons, and 0.9 kg particulates. The solid wastes, in addition to the arsenic previously mentioned, include up to 68 metric tons (75 tons) of spent HDN catalyst annually.

Delayed Coker Unit

In t[illegible]layed coker unit (Figure 22) the heavy bottom oil from each of the oil recovery fractionators is converted into lighter fractions and byproduct coke. The naphtha and gas are returned to the Gas Recovery Unit, the gas oil is fed to the Gas Oil Hydrogenation Unit, and the condensed water is sent to the Foul Water Stripper. Approximately 725 metric tons (800 tons) of coke is expected to be produced daily. Pending establishment of a market for this coke, it will be stored on the processed shale pile.

The estimated hourly atmospheric emissions from the cracking furnace of the Unit are as follows: 1.3 kg SO_2, 3.8 kg NO_x, 0.5 kg CO, 0.5 kg particulate matter, and 90 grams total hydrocarbons.

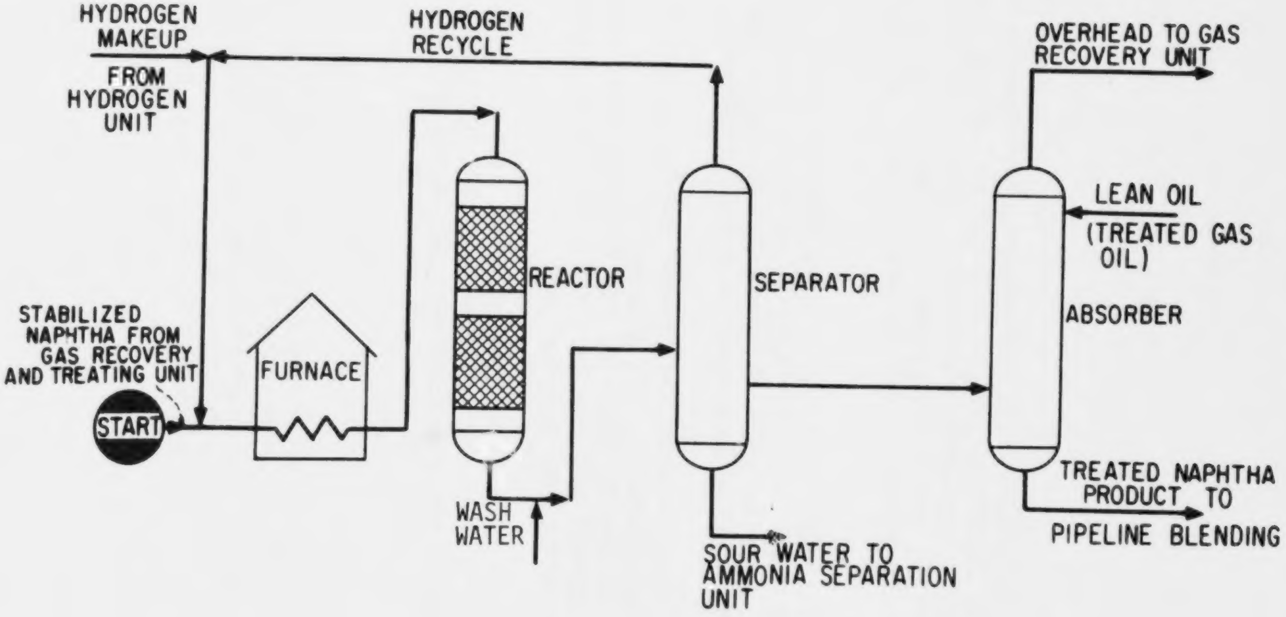

HYDROGEN MAKEUP
FROM HYDROGEN UNIT
HYDROGEN RECYCLE
OVERHEAD TO GAS RECOVERY UNIT
LEAN OIL
(TREATED GAS OIL)
STABILIZED NAPHTHA FROM GAS RECOVERY AND TREATING UNIT
START
FURNACE
REACTOR
SEPARATOR
ABSORBER
WASH WATER
SOUR WATER TO AMMONIA SEPARATION UNIT
TREATED NAPHTHA PRODUCT TO
PIPELINE BLENDING

Figure 21. Naphtha Hydrogenation Unit

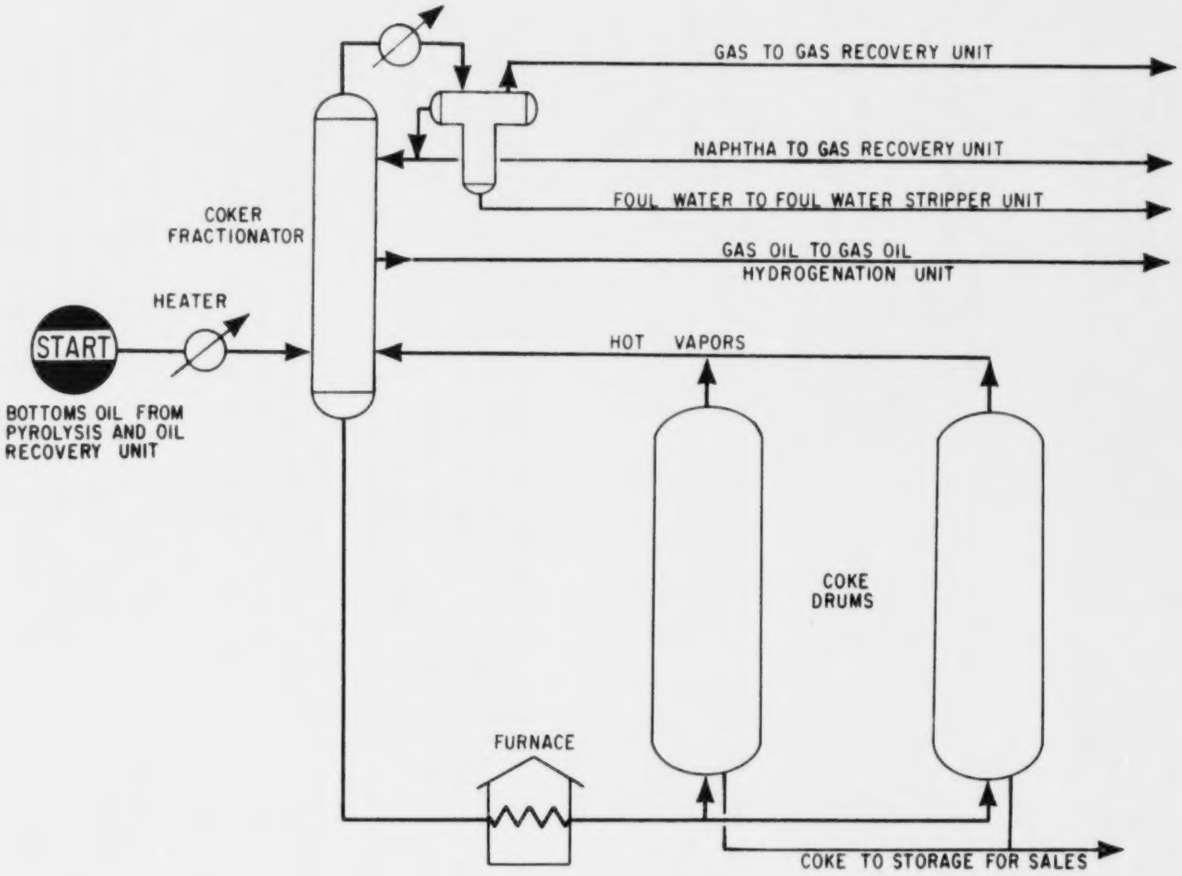

GAS TO GAS RECOVERY UNIT
NAPHTHA TO GAS RECOVERY UNIT
FOUL WATER TO FOUL WATER STRIPPER UNIT
COKER FRACTIONATOR
GAS OIL TO GAS OIL HYDROGENATION UNIT
HEATER
START
HOT VAPORS
BOTTOMS OIL FROM PYROLYSIS AND OIL RECOVERY UNIT
COKE DRUMS
FURNACE
COKE TO STORAGE FOR SALES

Figure 22. Delayed Coking Process

Ammonia Separation Unit

The sour water from the hydrotreaters is treated in the Ammonia Separation Unit (Figure 23) to remove hydrogen sulfide which is sent to the Sulfur Recovery Unit. Ammonia is then removed in an ammonia stripper, and compressed and cooled to liquid ammonia for sale. Some 122 metric tons (135 tons) of anhydrous ammonia are estimated to be produced daily. The stripped water is returned to the hydrotreaters or used to moisturize the processed shale. There are no expected atmospheric emissions or other effluents from this Unit.

Sulfur Recovery Unit

The acid gases from the Ammonia Separation, Foul Water Stripper, Gas Recovery and Treating Units are fed to two conventional Claus-type Sulfur Recovery trains to convert H_2S to liquid elemental sulfur. Some 176 metric tons (194 tons) of sulfur are expected to be produced daily. The tail gases from the Claus trains are fed to a standard Wellman-Lord sulfur recovery process to further reduce their residual sulfur content to approximately 250 ppm by volume. The SO_2 produced is recycled to the Claus trains.

There are no air emissions from the Claus trains, but 42.9 kg/hr of SO_2 are estimated to be emitted to the atmosphere from the Wellman-Lord processing unit. Also, approximately 68 metric tons/year (75 tons/year) of spent alumina catalyst from the Claus trains disposed of on the processed shale pile are expected.

DISPOSAL OF SOLID WASTES

Some 18,300,000 metric tons (20,200,000 tons)* of solid plant wastes must be disposed of annually, or an average of 50,000 metric tons (55,000 tons) daily. Some 97% of this waste, or 48,300 metric tons (53,300 tons) per day, is processed shale (and its dust). An additional 385 metric tons (425 tons) per day is raw shale dust. The remaining solids are spent catalyst materials, sludges, arsenic-laden solids, and processed plant sanitary wastes.

The processed shale is to be transported by closed conveyor to Davis Gulch (Figure 14) where a processed shale embankment will be created in the form of a compacted land fill with a typical average density of 1,360 kg/cubic meter (85 lbs/cu ft). A drainage system will be provided together with a catchment basin for run-off.

After final contours are established, contained salts in the top of the pile will be leached down into the pile, a 15 cm (6 in) layer of topsoil added, and a revegetation program initiated. The latter will include the requisite chemical fertilization and irrigation over a period of years to insure a stable, self-sufficient soil cover of about 45% grasses, 40% shrubs, and 15% forbs.

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*Figures are given on an equivalent, moisture-free basis, exclusive of the water content of moisturized processed shale and shale dust sludges.

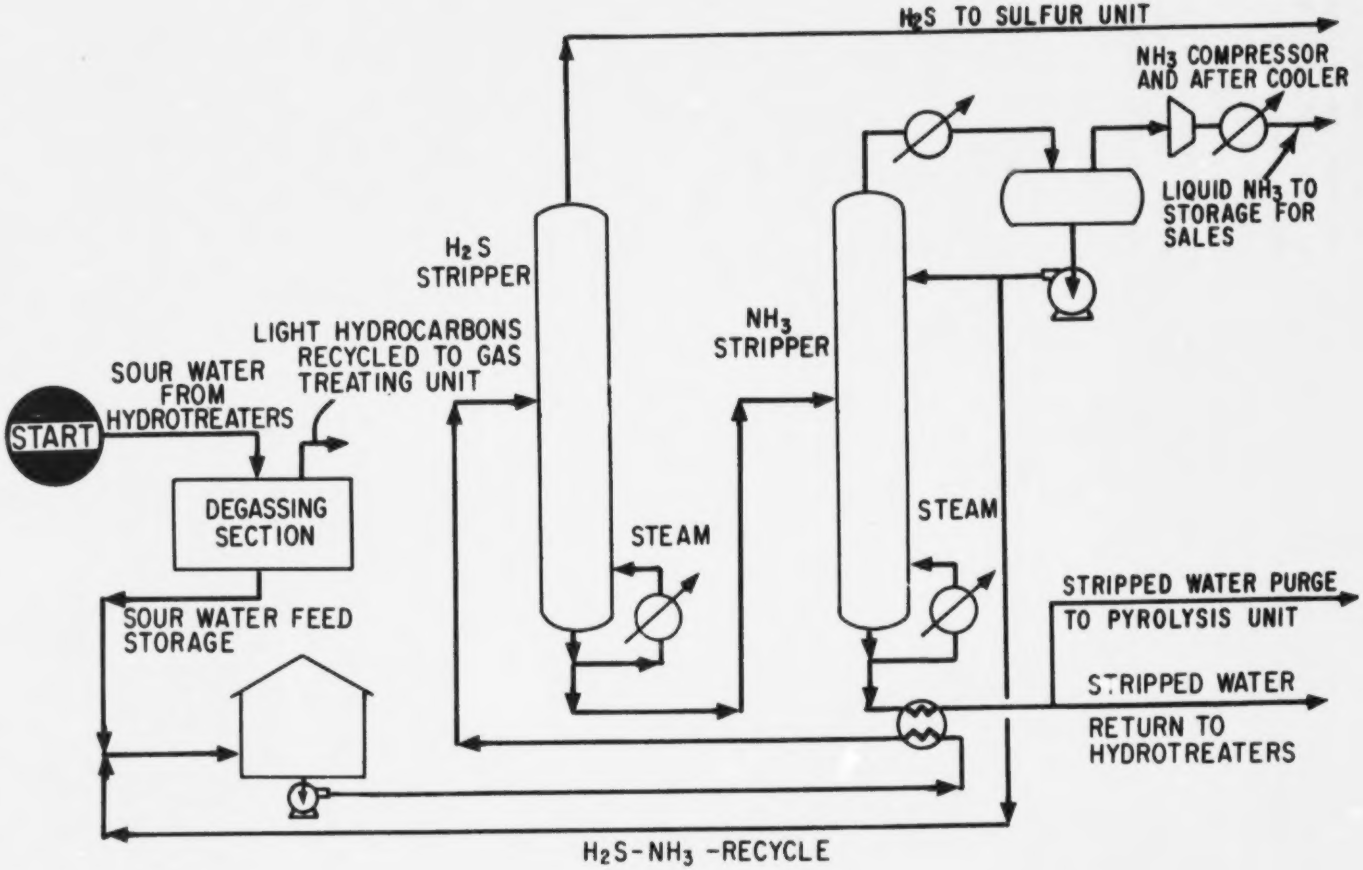
H_2S TO SULFUR UNIT
NH_3 COMPRESSOR AND AFTER COOLER
LIQUID NH_3 TO STORAGE FOR SALES
H_2S STRIPPER
NH_3 STRIPPER
LIGHT HYDROCARBONS RECYCLED TO GAS TREATING UNIT
SOUR WATER FROM HYDROTREATERS
START
DEGASSING SECTION
STEAM
STEAM
SOUR WATER FEED STORAGE
STRIPPED WATER PURGE
TO PYROLYSIS UNIT
STRIPPED WATER
RETURN TO HYDROTREATERS
H_2S-NH_3 -RECYCLE

Figure 23. Ammonia Separation Unit

SUPPORTING REQUIREMENTS

The proposed commercial plant will require diversion of 0.35 cubic meters/sec (12.5 cubic ft/sec) of water for consumptive use from the Colorado River. Two 230 kv power lines must be built (to insure no interruptions) by Public Service Company of Colorado to satisfy the 100 Megawatt plant operational load. A 24 km (15 mile) service corridor must be provided in Parachute Creek Valley, from the plant site southward to Grand Valley, Colorado, to permit construction of three pipelines (water, ammonia, LPG) and a two-lane highway. A 40 cm (16 in) diameter product pipeline some 310 km (194 miles) long to Lisbon Valley Station, Utah is proposed with connections to a major interstate pipeline at Aneth, Utah.

THE LURGI-RUHRGAS PROCESS FOR OIL SHALE RETORTING

C. C. Shih

Lurgi has been engaged in the development of oil shale retorting technology for approximately forty years, beginning with the design and installation of two tunnel kilns in co-operation with an Estonian shale oil company in the late 1930's. In this design, the oil shale was retorted in wagonetts which were pulled at short intervals through the tunnel kiln. In the ensuing years, several other oil shale retorting processes were developed by Lurgi to commercial stage. These included: a low temperature carbonization process (the Lurgi-Spülgas kiln); a batch process in which lumpy oil shale was distilled in retorts by sucking air through it from top to bottom (the Lurgi-Schweitzer process); a continuous process in which the shale traveled slowly on an inclined oscillating grate through the retort chamber and was distilled by air drawn through the shale bed from top to bottom across the length of the chamber (the Hubofen); and a fluidized-bed process involving the combustion of fine-grained oil shale for the direct generation of electricity (the Rohrbach-Lurgi process).

The Lurgi-Ruhrgas process was originally developed by Lurgi in collaboration with Ruhrgas AG in the 1950's for the production of pipe-line quality gas by the devolatilization of coal fines. The process utilizes circulating solid heat carriers for retorting and has been applied on the commercial scale for the devolatilization of lignite fines, the production of char fines for hot briquetting from subbituminous coal, and the cracking of naphtha and crude oil to produce olefins. To demonstrate the applicability of the process for the distillation of oil shale, Lurgi has carried out a number of pilot plant tests at the Herten works in the Ruhr district of Germany. Two test series with Colorado oil shale were conducted in 1967 and 1968 when approximately 45 tonnes* (50 tons) of oil shale over a one week period and 220 tonnes (240 tons) of oil shale over a three week period were distilled. The oil shale charged to the pilot plant was in the 0 to 0.635 cm (0.25 in) and 0 to 1.27 cm (0.5 in) size range and had a Fischer assay from 10.2 to 12.6 percent (equivalent to 27-33 gal/ton). The pilot tests showed that at temperatures of about 530°C (986°F) and optimum throughout feed rates, high oil yields of over 100 weight percent of those indicated by the Fischer assay could be attained in the retorting steps.

American Lurgi Corporation and Dravo Corporation have recently presented a proposal to fourteen major oil shale land owners and leasees seeking industry support of a project to demonstrate the Lurgi-Ruhrgas process at the 3,630 tonnes/day (4,000 tons/day) level, at an estimated cost of $25 to $30 million. The 3,630 tonnes/day demonstration plant is considered by Lurgi to be a fully commercial-scale module, and a commercial plant would consist of a number of such modules. In the proposed plan, Lurgi estimated that the demonstration plant could be operational 36 months after project approval. Lurgi was recently commissioned to provide two 3,630 tonnes/day plants for the processing of oil shale in Bulgaria. These plants are similar to those proposed for the processing of Colorado oil shale, except the minor modifications made to accommodate a different type and grade of shale. In addition, American Lurgi Corporation and Dravo Corporation have also presented a proposal for the design, construction and operation of a 907 tonnes/day (1,000 tons/day) demonstration plant for the Lurgi-Ruhrgas process to smaller companies.

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*1 Tonne - 1,000 kg

Mining and Crushing

The mining and crushing operations for the Lurgi-Ruhrgas process will be similar to those for the other above-ground retorting processes. The conventional room-and-pillar method will probably be used for production mining of the shale. Both primary and secondary crushing of the shale may be performed underground. Primary crushing will reduce the size of the run-of-mine shale to minus 20 cm (8 in), and secondary crushing will further reduce the shale size to minus 6 mm (0.25 in). It may also be noted that fine-grained oil shale rejected as feed for other retorting processes is ideally suited as feed for the Lurgi-Ruhrgas process.

Retorting and Upgrading

In the Lurgi-Ruhrgas process, shown in Figure 24, crushed oil shale of minus 6 mm (0.25 in) size is fed through a feed hopper to a double screw mixer, where it is intimately mixed with 6 to 8 times its volume of the hot circulating shale residue at 630°C. The fresh shale feed is heated to 530°C within a few seconds, resulting in the evolution of gas, shale oil vapor and water vapor. The circulating heat carrier and the partially retorted, fresh shale feed are then dropped from the screw mixer into the surge hopper where residual oil components are distilled off.

The mixture of heat carrier and retorted shale residue is passed through to the lower section of the lift pipe where combustion air at 400°C is introduced, raising the mixture pneumatically to the collecting bin, and burning the carbon contained in the retorted shale residue during the transport process. The heat carrier is now separated from the flue gases in the collecting bin. The fines are carried through with the flue gas stream, whereas the coarse grained shale residue accumulates in the lower section of the collecting bin and flows from there continuously to the mixer. The combustion air supplied to the lift pipe is preheated by countercurrent heat exchange with the flue gas stream.

The volatile gas product stream from the retorting of the oil shale is passed through two series - connected cyclones, and the dust separated in these cyclones is returned to the recycle system. The gas stream then enters a sequence of three scrubbing coolers. The first scrubbing cooler is designed to operate at higher temperature to remove the residual dust from the gas stream by washing and circulating condensed heavy oil. In the next scrubbing

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NOTE: Figure 24 is obtained from Reference 1.

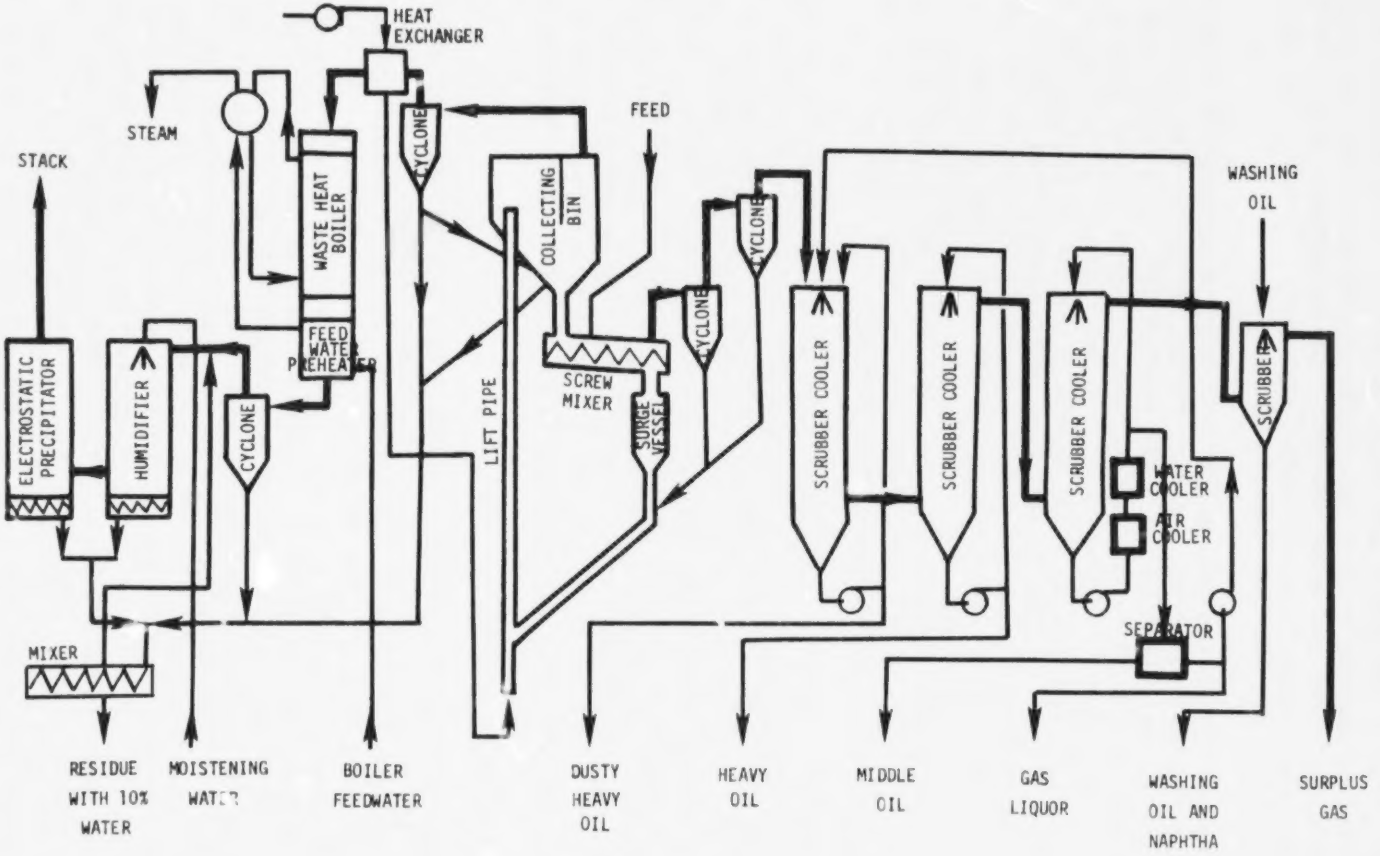
HEAT EXCHANGER
STEAM
STACK
FEED
WASHING OIL
WASTE HEAT BOILER
FEED WATER PREHEATER
CYCLONE
COLLECTING BIN
CYCLONE
CYCLONE
SCRUBBER COOLER
SCRUBBER COOLER
SCRUBBER COOLER
SCRUBBER
ELECTROSTATIC PRECIPITATOR
HUMIDIFIER
CYCLONE
LIFT PIPE
SCREW MIXER
SURGE VESSEL
WATER COOLER
AIR COOLER
SEPARATOR
MIXER
RESIDUE WITH 10% WATER
MOISTENING WATER
BOILER FEEDWATER
DUSTY HEAVY OIL
HEAVY OIL
MIDDLE OIL
GAS LIQUOR
WASHING OIL AND NAPHTHA
SURPLUS GAS

Figure 24. The Lurgi-Ruhrgas Process for the Retorting of Oil Shale

cooler, major condensation of the oil takes place at a temperature above the dew point of water to produce a dust-free heavy oil. Final cooling is by circulating the condensate in the last scrubbing cooler, after the condensate has been recooled in air and water coolers. The condensate is separated into middle oil and gas liquor in an oil/water separator. Finally, the gas is scrubbed with light oil for the recovery of naphtha.

The flue gas stream evolved in the lift pipe is dedusted in a cyclone after leaving the collecting bin and then routed through a heat exchanger for the preheating of combustion air, a waste heat boiler, a feedwater preheater, another cyclone, a humidifier and an electrostatic precipitator before discharge to the atmosphere. In the humidifier the flue gas stream is cooled from approximately 320°C to 150°C by water injection, and a portion of the shale dust contained in the flue gas is separated and discharged to a chain conveyor. The residual dust is removed from the flue gas stream in the electrostatic precipitator and discharged onto another chain conveyor. The two chain conveyors then carry the fine dust from the cyclone, heavy oil dust from the heavy oil dust removal step, and moistening water to a combined residue mixer. The final spent shale residue requiring disposal has a moisture content of 10 to 12% water and a temperature of 65°C.

The dust-laden heavy oil obtained in the first scrubbing cooler is freed of dust by sedimentation and centrifuging after addition of naphtha to reduce the viscosity of the heavy oil. The final products obtained include a dust-free heavy oil, a middle oil, a gas naphtha, and a distillation gas. The properties of these hydrocarbon products are presented in Table 6 (Reference 1). However, information on the ash, arsenic, sulfur and nitrogen content of the liquid products is not presently available from Lurgi. This information is necessary to the estimation of the type and quantity of waste streams, as well as the capital investment costs and the utilities requirements associated with the upgrading of the crude shale oil produced by the Lurgi-Ruhrgas process.

Air, Water and Solid Wastes

The major atmospheric emission stream from the Lurgi-Ruhrgas process is the flue gas from the combustion of the shale residue. For a 7,950 m^3 per stream day (50,000 BPSD) plant, the amount of flue gas released to the atmosphere is estimated to be 724,400 Nm^3/hr (27 MMSCFH). In the pilot plant tests conducted by Lurgi there were only two cyclones available for removing particulates from the flue gas. As a result, the flue gas discharged from the cyclones still contained approximately 20 g/Nm^3 of particulates with particle diameter of less than 40 μ (Reference 2). This was equivalent to a particulate collection efficiency of 95%. In Lurgi's assessment, particulate collection efficiencies of up to 99.98% are achievable by the addition of electrostatic precipitators based on the measurement of the electrical resistance of the particulates in the flue gas atmosphere and temperature during the pilot plant tests and Lurgi's experience with over 300 commercial electrostatic precipitator installations. In the pilot plant tests, it was also found that the SO_2 content of the flue gas was only approximately 30 mg/Nm^3 (10.5 ppm). This was probably because the major portion of the SO_2 released during combustion was recaptured by the CaO and MgO formed and discharged with the retorted shale. NO_x measurements of the flue gas were not

Table 6. Properties of Oil Shale Retorting Products

a) Heavy Oil (dust free):

Density$_{(50^\circ C)}$	kg/l	0.954
Viscosity$_{(50^\circ C)}$	cP	98
Flash point	°C	153
Settling point	°C	24
Conradson test	wt%	8
Initial boiling point (at 760 Torr)	°C	130

b) Middle Oil:

Density$_{(20^\circ C)}$	kg/l	0.818
Viscosity	cP	1.25
Flash point	°C	<+20
Settling point	°C	<-40
Conradson test	wt%	0.42
Initial boiling point (at 763 Torr)	°C	70
Final boiling point (at 763 Torr)	°C	283

c) Gas Naphtha:

Density$_{(20^\circ C)}$	kg/l	0.699
FIA analysis:		
Aromatics and diolefins	vol%	84.4
Olefins	vol%	1.7
Paraffins	vol%	13.9
Initial boiling point (at 738 Torr)	°C	36
Final boiling point (at 738 Torr)	°C	137

d) Distillation Gas (Naphtha Free)

Net calorific value kcal/Nm^3 7,150

Composition:

CO_2	vol%	28.8
CO	vol%	3.1
H_2	vol%	21.3
N_2	vol%	8.9
C_1	vol%	13.7
C_2	vol%	13.8
C_3	vol%	10.3
H_2S	g/Nm^3	2.28
SO_2	g/Nm^3	0.07

made during the pilot plant tests. Measurements on the combustion products from a commercial fluidized-bed oil shale combustion plant (the Rohrbach-Lurgi process) in South Germany, however, indicated that the combustion product contained only approximately 100 ppm of NO and no detectable NO_2. Since the fluidized-bed combustion of the oil shale took place in an oxidizing atmosphere and at a much higher temperature (approximately 800°C) than the combustion temperature of the shale residue in the Lurgi-Ruhrgas process (below 700°C), the NO_x content of the flue gas stream from the Lurgi-Ruhrgas process is expected to be lower than 100 ppm.

The major liquid waste stream from the Lurgi-Ruhrgas process is the gas liquor produced in the distillation of the oil shale. The rate of gas liquor production is estimated to be 38.53 m^3/hr (170 gpm), for a 7,950 m^3 per stream day (50,000 BPSD) plant. The gas liquor contains minor amounts of ammonia, oil and phenols, and is used for cooling and moistening of the spent shale. Lurgi indicates that the minor contaminants present in the gas liquor will be absorbed by the shale residue without posing an environmental problem. For this reason, treatment of the gas liquor by oil separation and by stripping to remove the ammonia and hydrogen sulfide components, has not been included in the Lurgi process scheme.

The major solid waste streams from the Lurgi-Ruhrgas process include the heavy oil dust discharged from the dryer in the heavy oil dust removal step, and the retorted shale. For a 7,950 m^3 per stream day (50,000 BPSD) plant, 1,270 tonnes (1,400 tons) of heavy oil dry dust and 39,700 tonnes (43,770 tons) of retorted shale are generated per day. The heavy oil dust is almost completely free of oil and can be dumped together with the retorted shale after moistening water and the gas liquor are added to increase the moisture content of the retorted shale to approximately 10%. At the present time, Lurgi has not provided any information on the detailed characterization of the gas liquor and the shale residue.

Oil Shale Retorting Products and Utilities Requirements

For a commercial size plant processing 51,377 tonnes (56,633 tons) of 35.7 gpt oil shale per stream day, the Lurgi-Ruhrgas process will generate the following products.

Shale Oil: 7,950 m^3/(50,000 bbl) per stream day

Make Gas (naphtha free): 47,780 Nm^3/hr (1.78 MMSCFH)

Retorted Shale (dry basis): 40,970 tonnes (45,160 tons) per stream day

Waste Water (contained in the spent shale residue): 183 m^3/hr (806 gpm)

The total water consumption rate is estimated by Lurgi to be 334 m^3/hr (1,470 gpm) and the power requirement to be 28,770 kw (Reference 2). The fuel requirement for the retorting of the oil shale will be met by the combustion of the retorted shale residue. It may be noted that the mining and crushing of the oil shale, the recovery and treatment of the make gas, and the upgrading of the crude shale oil product are not included in the estimation of the utilities requirements provided above.

REFERENCES

1. Schmalfeld, P., The Use of the Lurgi-Ruhrgas Process for the Distillation of Oil Shale, Quarterly of the Colorado School of Mines, 70 (3): 129-145, July 1975.

2. Development of the Lurgi-Ruhrgas Retort for the Distillation of Oil Shale, Lurgi Mineraloltechinek GMBH, Frankfurt (Main), October 1973.

SUPERIOR OIL SHALE PROCESS

Charles H. Prien

The Superior Oil Shale Process is unique among current, potential industrial U.S. shale processing methods in two respects, i.e., its recovery of saline minerals and its use of a circular grate retort. Superior has 2645 hectares (6500 acres) of private shale holdings on the northern edge of Colorado's Piceance Creek basin (Figure 25). The tract contains substantial quantities of the saline minerals nahcolite ($NaHCO_3$) and dawsonite ($NaAl(OH)_2CO_3$) in addition to oil shale. Most of these saline minerals occur in the Lower Zone of the Parachute Creek member of the Green River Formation, 500-760 meters (1700-2500 ft) below the surface.

UNDERGROUND MINING, CRUSHING, NAHCOLITE RECOVERY

A porous, highly fractured "leached" zone, located above the Lower Zone oil shales and their associated saline minerals, is at present filled with strongly saline water. Sinking a vertical shaft through this zone to the underlying deep oil shale strata and its associated saline minerals does not appear economically desirable. Superior proposes instead to drive a 9° incline adit some 4 kilometers (2.5 miles) long from the surface to the 610 meter (2,000 ft) deep shale beds, beginning at a surface outcrop point outside the area of the "leached" zone aquifer (Figure 26). This incline adit with a cross-section of 3.6 meters by 6.1 meters (12 ft by 20 ft) would be below the dish-shaped "leached" zone strata, and would therefore reach the lower oil shale zone without the necessity of passing through the aquifer.

Multi-level underground mining at a rate of 22,700 metric tons/day (25,000 tons/day) will be done using the room and pillar method. In order to provide protection against unforeseen leakage, especially from the "leached" zone aquifer some 155 meters (510 ft) or more above the mining zone, the mine rooms will be grouped into a series of "panels" or cells 460 meters x 820 meters (1,500 ft x 2,600 ft) (Figure 27) with each cell enclosed entirely (except for an entrance) by a rib pillar (barrier wall). Panels within a level will be aligned with corresponding panels in levels above and/or below. In the event of excessive water leakage into a cell it can thus be sealed off from the balance of the mine.

Nahcolite producing levels will be mined with an estimated face height of 12 meters (40 ft). Oil shale levels with little or no nahcolite will have an estimated height of 60 feet. Approximately 55-65% of the mineable zone is

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Note: Illustrations are from Weichman, B., Colorado School of Mines Quarterly 69, No. 2, 25-44 (1974); and Superior Oil Company.

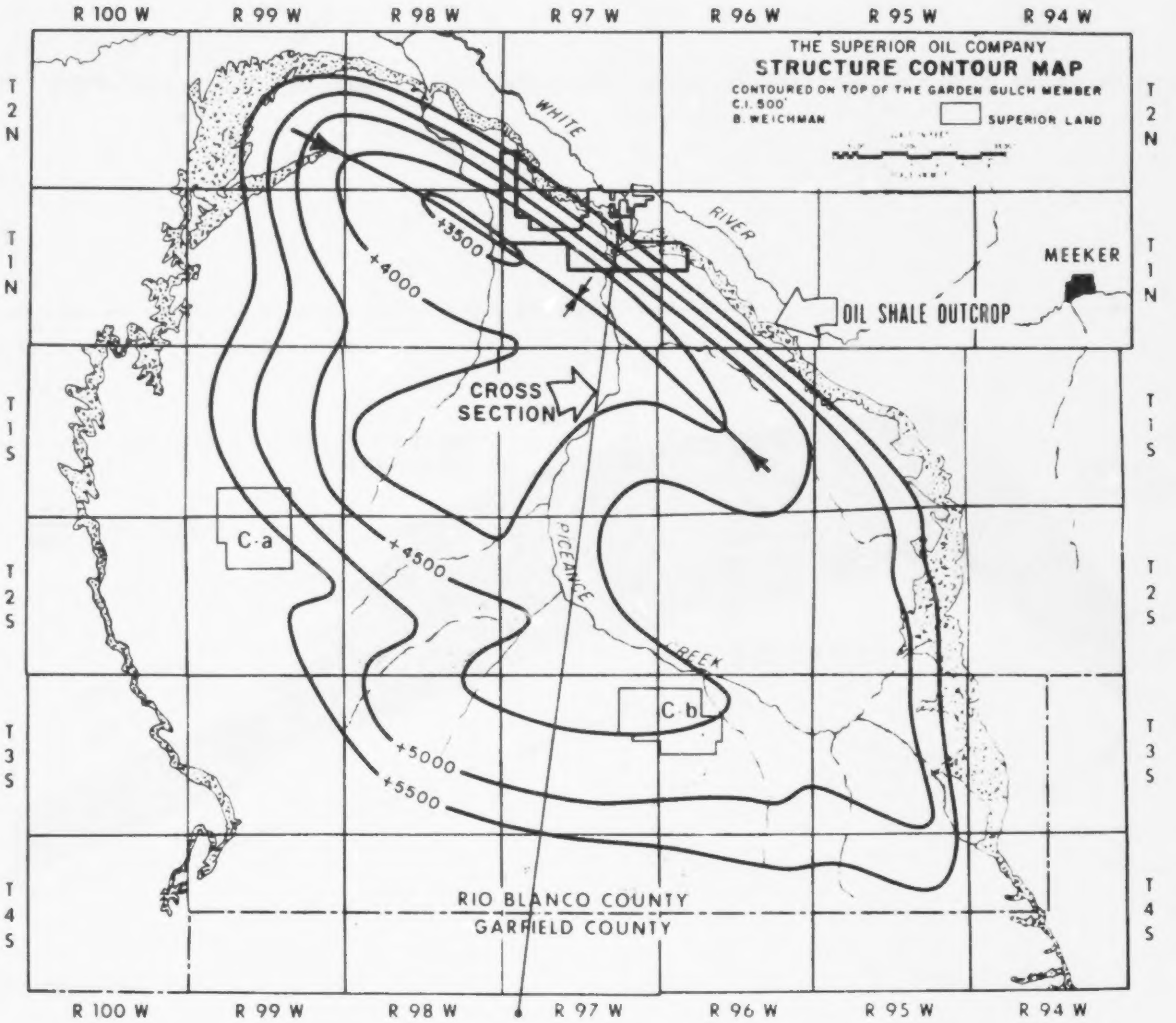
THE SUPERIOR OIL COMPANY
STRUCTURE CONTOUR MAP
CONTOURED ON TOP OF THE GARDEN GULCH MEMBER
C.I. 500'
B. WEICHMAN
SUPERIOR LAND
R 100 W
R 99 W
R 98 W
R 97 W
R 96 W
R 95 W
R 94 W
T 2 N
T 1 N
T 1 S
T 2 S
T 3 S
T 4 S
WHITE
RIVER
MEEKER
OIL SHALE OUTCROP
+3500
+4000
+4500
+5000
+5500
CROSS SECTION
PICEANCE
CREEK
C-a
C-b
RIO BLANCO COUNTY
GARFIELD COUNTY

Figure 25. Structure Contour Map.

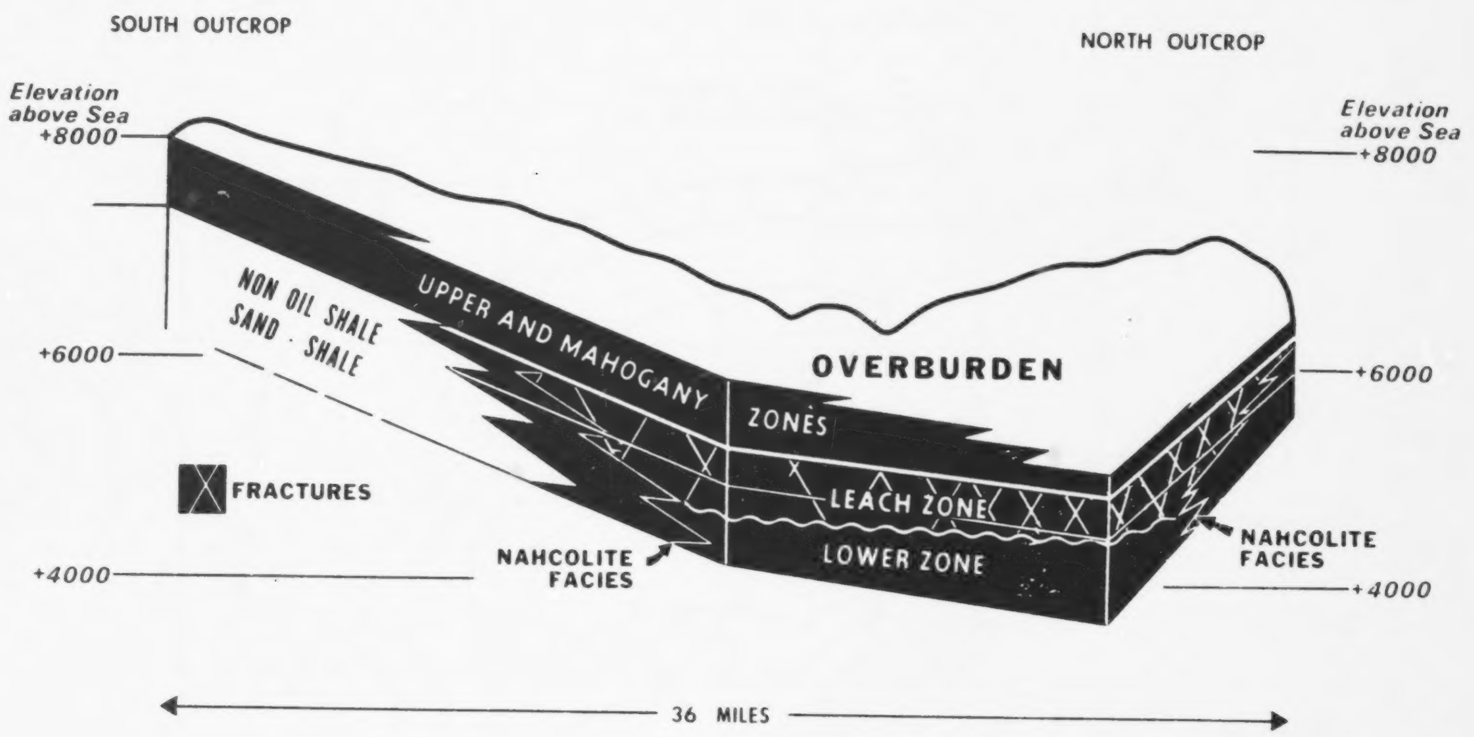
SOUTH OUTCROP
NORTH OUTCROP
Elevation above Sea +8000
Elevation above Sea +8000
+6000
+6000
+4000
+4000
UPPER AND MAHOGANY
ZONES
OVERBURDEN
LEACH ZONE
LOWER ZONE
NON OIL SHALE
SAND · SHALE
FRACTURES
NAHCOLITE FACIES
NAHCOLITE FACIES
36 MILES

Figure 26. Schematic Cross Section of the Parachute Creek Member Showing Three Zones in Oil Shale.

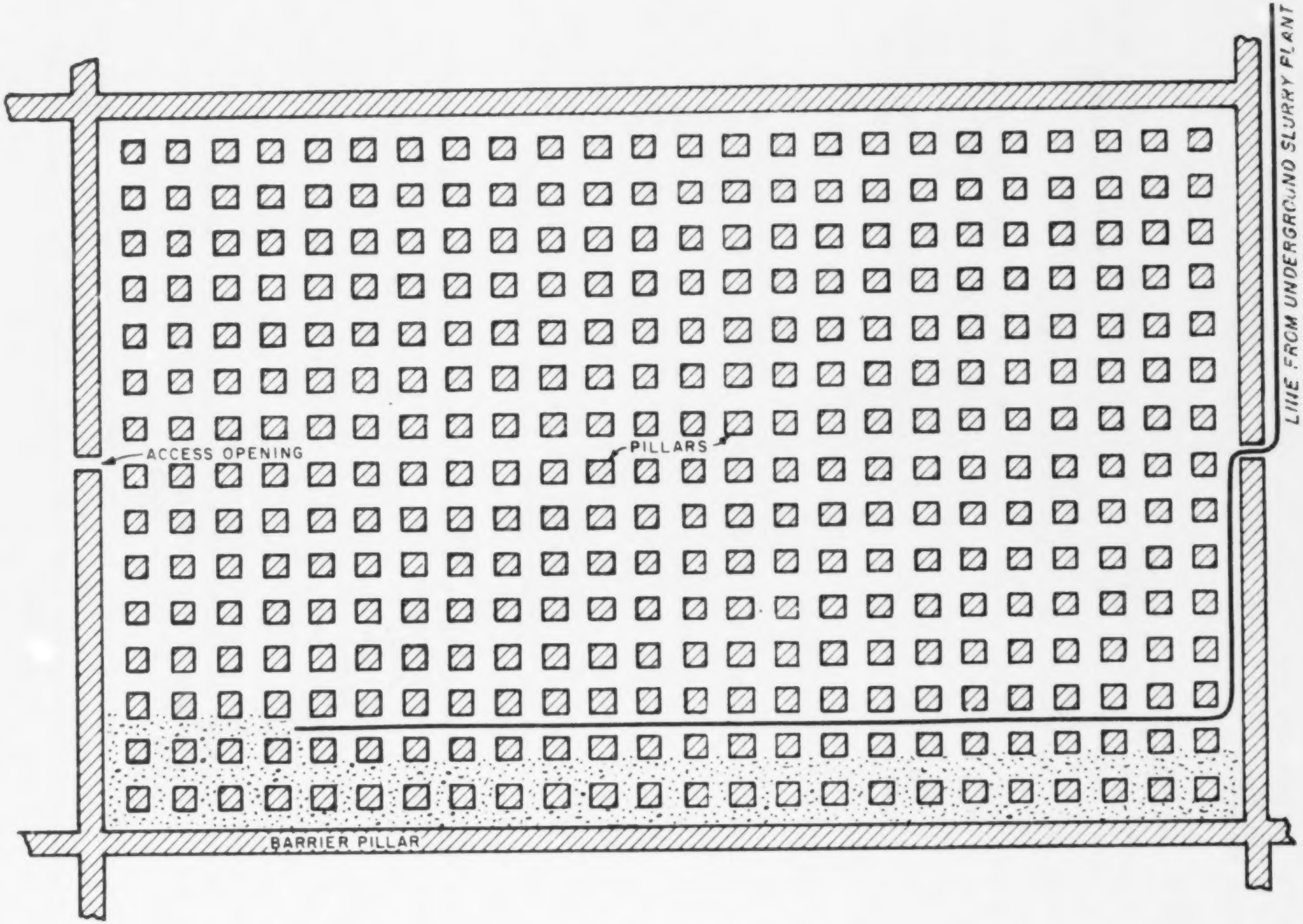
LINE FROM UNDERGROUND SLURRY PLANT
ACCESS OPENING
PILLARS
BARRIER PILLAR

Figure 27. Typical Mine Panel Showing Spent Shale Return.

expected to be removed for processing, depending upon the depth of the mine below the surface and the percentage of nahcolite in the shale. A typical mine-run raw shale from a nahcolite producing level as fed to the crushers is expected to average 20% nahcolite and 10% dawsonite.

Crushing

Primary crushing of the mine-run shale to minus 20 cm (8 in) will be done underground. Secondary crushing to minus 7.5 cm (3 in) size in Hazemag impact crushers can be done either underground or at the surface. Fugitive dust from the crushers will be removed by bag filters.

Eighty percent to 95% of the raw nahcolite will be separated from the shale by secondary crushing and screening. Upgrading of the nahcolite-rich fractions may be accomplished by photo-reflectance sorting. The nahcolite remaining in the shale is allowed to continue through the retorting process where it is calcined to soda ash and recovered in the subsequent leaching operations.

Retorting and Partial Refining

The three raw shale streams are fed to a travelling circular grate retort (Figure 28). The finest material, minus 25 mm plus 6 mm (minus 1" plus ¼"), is laid down first on the grate, followed by the minus 50 mm plus 25 mm (minus 2" plus 1"))intermediate fraction, and on top by the coarsest fraction, minus 7.5 cm plus 5 cm (minus 3" plus 2"). A commercial sized retort is estimated to be 56 meters (185 ft) in diameter with a capacity of 20,900 metric tons (23,000 tons) of feed per day. The bed depth of shale is expected to be some 135 cm (54 in). The retort would be gas-tight by virtue of simple but very effective water seals (Figure 29). An airlock system for loading raw shale and a water-sealed (airlock optional) dump system precludes exit of retort gas to the atmosphere.

The doughnut-shaped retort (Figure 30) is divided into five separately enclosed sections, viz a loading zone, a retorting zone, a residual carbon recovery zone, a cooling zone, and to complete the circle, an unloading zone adjacent to the original loading sector. In a typical operation the prepared bed of shale loading on the travelling grate passes first into the retorting zone, where the shale is contacted by a stream of hot (neutral or reducing) gases. The hot gases are drawn downward through the bed where they heat the shale to retorting temperature. The oil-vapor-laden gas mixture leaves the bed and passes to a separator-condenser system to remove the product shale oil. The oil-denuded and cooled recycle gases then pass through the retorted shale bed in the cooling zone of the retort to cool the shale before dumping, and then directed to the combustion zone.

The retorted shale travels from the retorting zone to the residual carbon recovery (or combustion) zone where it is contacted with steam and air to form producer gas by reaction with the carbon residue. This producer gas provides fuel for the utility plant.

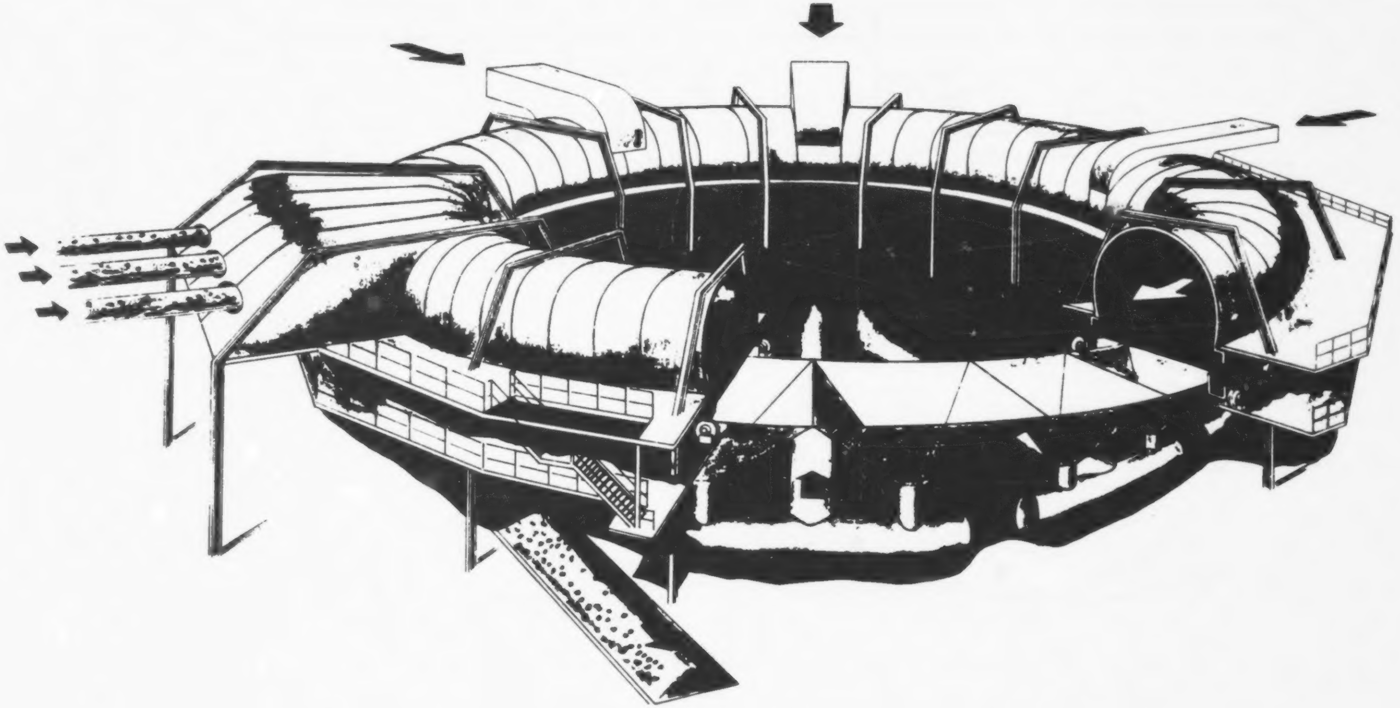

Figure 28. Artist's Conception of Circular Grate Retort.

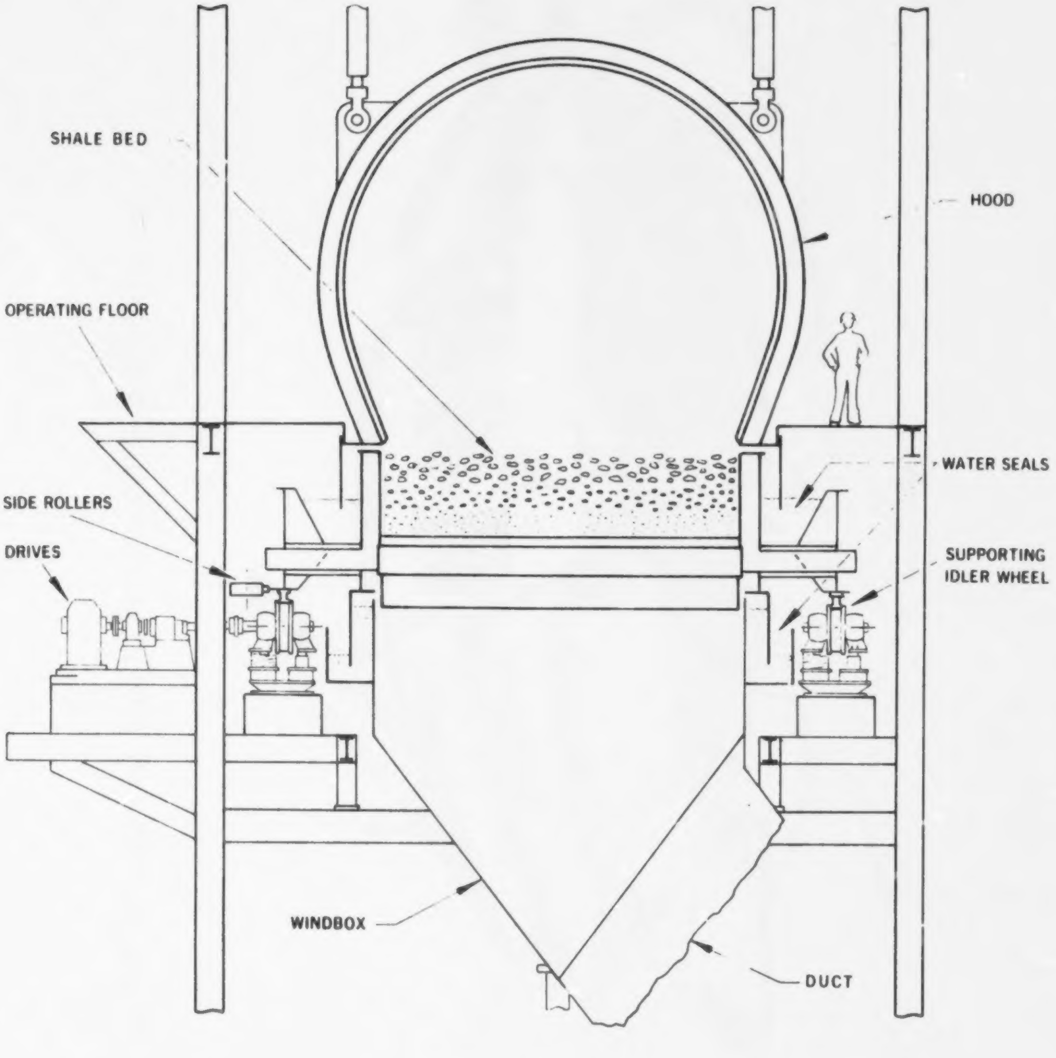
SHALE BED
HOOD
OPERATING FLOOR
WATER SEALS
SIDE ROLLERS
DRIVES
SUPPORTING IDLER WHEEL
WINDBOX
DUCT

Figure 29. Cross Section of Circular Grate Retort. (Courtesy Arthur G. McKee & Co.)

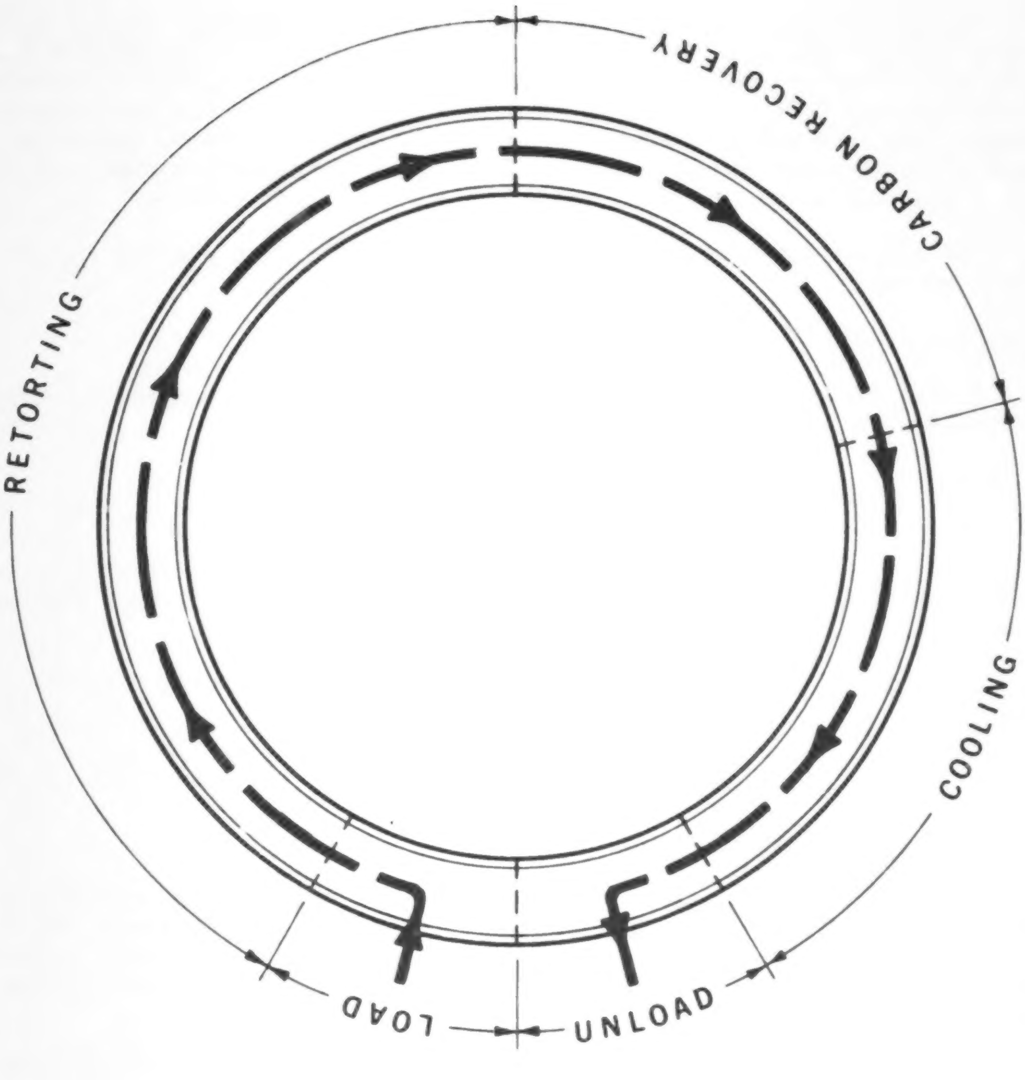
CARBON RECOVERY
RETORTING
COOLING
LOAD
UNLOAD

Figure 30. Plan View of Circular Grate Retort Showing Movement of Charge thru Various Zones.

The retorted shale travels to the retort cooling zone where its temperature is reduced. It then moves to the unloading zone where it is discharged from the retort and sent to the leaching plant for recovery of alumina and soda.

The product shale oil, 2380 cu meters/day (15,000 bbl/day) from a 18,100 metric ton/calendar day (20,000 TPCD) total plant input, is expected to have a gravity of 26° API and a pour point of 21°C (70°F). It typically contains 2% nitrogen and 0.8% sulfur without further treatment. It has been proposed, however, that the sulfur content can be considerably reduced by including crude nahcolite with the dawsonitic shale fed to the retorting zone. If this is not done the sulfur could be removed in subsequent processing.

The only energy produced off site and consumed in the process is electrical energy.

Alumina and Soda Ash Recovery

During the retorting of the dawsonitic oil shale, the dawsonite present is converted to alumina and sodium carbonate:

$$2NaAl(OH)_2CO_3 \xrightarrow{heat} Al_2O_3 + Na_2CO_3 + CO_2 + 2\ H_2O$$

This reaction occurs between about 370°C and 670°C (700°F and 1240°F).* Precise temperature control is necessary to optimize the solubility of the aluminum oxide.

The residual nahcolite in the raw shale is calcined during retorting to soda ash:

$$2NaHCO_3 \xrightarrow{heat} Na_2CO_3 + CO_2 + H_2O$$

which also remains in the spent shale.

In order to recover the aluminum and sodium compounds, the cooled spent shale from the retort is crushed and fed to countercurrent decanters where it is dissolved in an alkaline leach solution. Recirculated carbonate liquor and make-up water from the "leached" zone form the leach solution. Sodium hydroxide may be added to adjust the pH.

The alumina in the spent shale is solubilized by the caustic solution to sodium aluminate:

$$Al_2O_3 + 2NaOH \longrightarrow 2NaAlO_2 + H_2O$$

After leaching, the spent shale is washed, separated from the liquor and returned to the mine for disposal (see following paragraph).

---

*Shale retorting temperature is 425-480°C (800-900°F)

After filtration, the highly saturated sodium aluminate liquor is nucleated and carbonated to precipitate alumina trihydrate:

$$2NaAlO_2 + CO_2 + 3H_2O \longrightarrow Na_2CO_3 + Al(OH)_3$$

The insoluble $Al(OH)_3$ is filtered from the carbonate-rich liquor and the crystals sent to a calciner for conversion to cell grade alumina:

$$2Al(OH)_3 \xrightarrow{heat} Al_2O_3 + 3H_2O$$

The carbonate-rich liquor is decolorized and then fed to a multiple-effect evaporator to remove the water and produce soda ash crystals (Figure 31). These are centrifuged from the mother liquor and dried for sale. Impurities in the recovery system circuit are periodically purged, and the purged solution is added to the spent shale for underground disposal. The water vapor from the evaporators is recovered as pure water by condensers for use wherever high-grade, potable water is needed.

Processed Shale Disposal

In the Superior multi-mineral process, over 40% of the original mined volume of rock is "consumed" in producing shale oil, alumina, soda ash and nahcolite. As a result of the volume reduction, all of the remaining processed shale can be returned underground, thus eliminating both surface disturbance due to spent shale discard piles and the need for revegetation.

Superior proposes to return the leached shale to the mine as a wet cake on the flip side of the production conveyor. An underground slurry plant would prepare the shale for emplacement. The slurry water will be recycled to and from the slurry plant with make-up water obtained from the "leached" zone aquifer.

The slurry is pumped into the underground "rooms" between the pillars (Figure 27) and allowed to drain to approximately 25% moisture content. Because of the dipping beds, the slurry can be emplaced to the ceiling by strategic withdrawal of the slurry discharge pipe as the room fills. Refilling the mine with processed shale will eliminate pillar spalling, lateral creep, and post-mining fracturing.

Water Requirements

The Superior multi-mineral process will produce the following products from 22,220 metric tons/day (24,500 TPD) of mined shale:

Shale oil: 1600 to 2380 cu meters/day (10,000 to 15,000 bbl/day)
Nahcolite: 4,360 metric tons/day (4,500 tons/day)
Cell Grade Alumina: 455-725 metric tons/day (500-800 tons/day)
Soda Ash: 725-945 metric tons/day (800-1,300 tons/day)

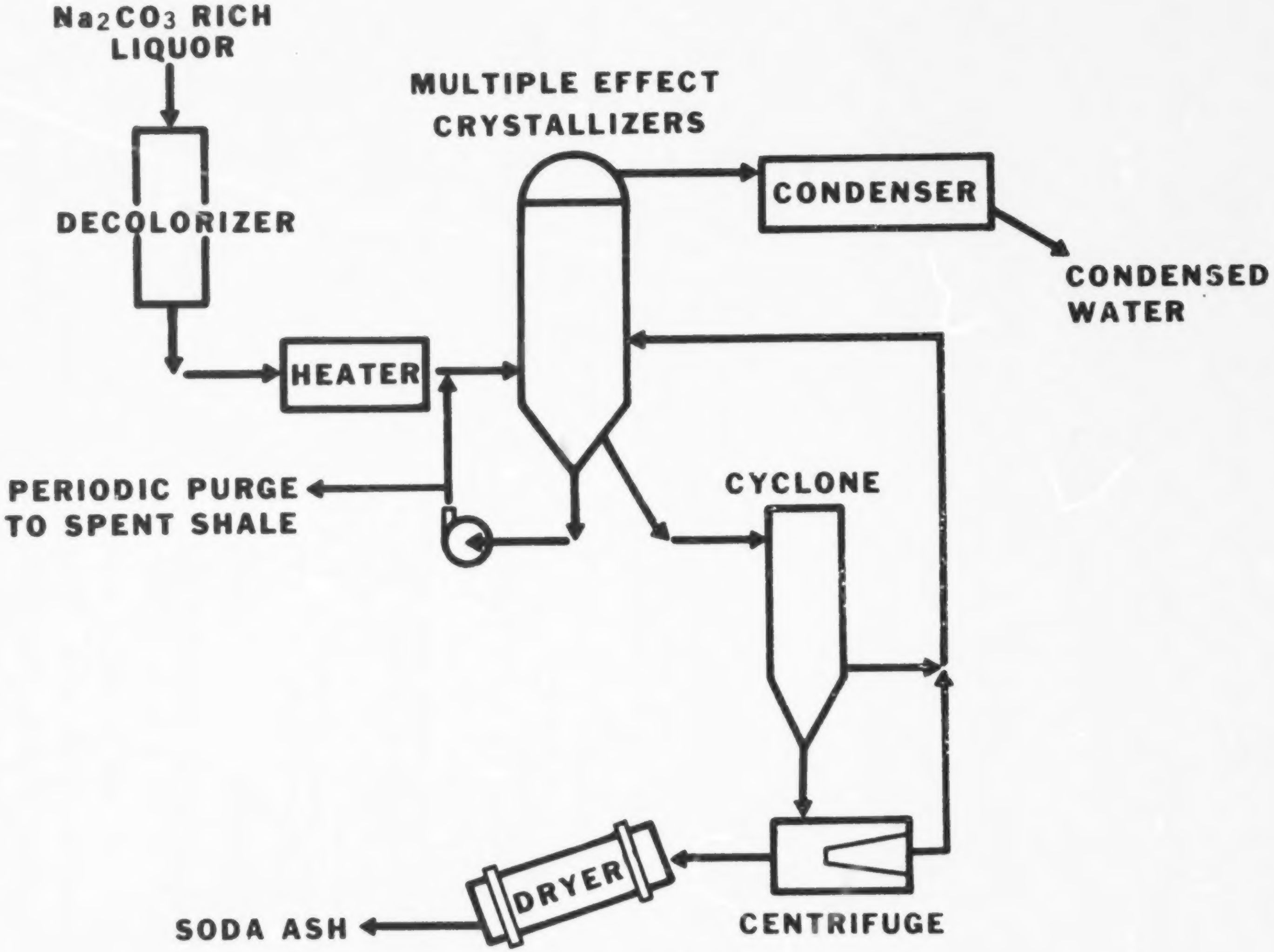
Na_2CO_3 RICH LIQUOR
DECOLORIZER
HEATER
MULTIPLE EFFECT CRYSTALLIZERS
CONDENSER
CONDENSED WATER
PERIODIC PURGE TO SPENT SHALE
CYCLONE
CENTRIFUGE
DRYER
SODA ASH

Figure 31. Conceptual Design Soda Ash Plant.

Total net consumptive water required for this production is estimated by Superior to be 4,760 metric tons (1.26×10^6 gal) per day, plus the additional generation of 3,540 metric tons per day of condensed water (make condensate) available for fresh water use. Of the 4,760 metric tons per day that is consumed, 3,475 metric tons per day (73%) is used for spent shale disposal, and 1,285 metric tons per day (27%) is consumed or evaporated in chemical processing.

All water requirements will be satisfied by the 27°C (80°F) saline water in the "leached" zone, including plant cooling water. After use, the 49°C (120°F) return cooling water, unaltered in chemical composition, would be injected back into the aquifer, possibly at a point of equal temperature and equal salinity. The cooling water recycled back into the "leached" zone aquifer represents 75% of the total daily water demand required to sustain the Superior process.

USBM GAS COMBUSTION PROCESS

Charles H. Prien

The Synthetic Fuels Act of 1944 authorized the construction and operation of demonstration plants for synthetic fuels, including oil shale. Under the Act, a number of experimental retorting systems were developed and tested at the U.S. Bureau of Mines Oil Shale Experiment Station at Anvil Points, Colorado. The most successful of these was the Gas Combustion retort which is the subject of this Overview Report.

BACKGROUND

The gas combustion retorting process evolved from studies begun by the Bureau of Mines at Anvil Points in mid-1949. Previous retorting concepts tested had included the old NTU design, a Royster low temperature type, and a cross-flow configuration.

The initial gas combustion design was an internally-heated dual flow pilot unit 51 cm (20 in) I.D. by 3.5 meters (11.5 ft) high with downward gravity flow of raw shale. Heat was produced by burning a combination of recycled retort gases and the carbonaceous residue on the spent shale.

The recycle gases and air entered the bottom of the retort and were preheated by downflowing hot spent shale. They then passed upward into a combustion zone. The resulting hot combustion gases were withdrawn from the retort at the top of the combustion zone (prior to entering the retorting zone), and bypassed to the top of the retort where they passed downward in co-current flow with the raw shale, preheating and then retorting the shale. The resulting retort gases and shale oil mist were withdrawn from the retort at the bottom of the retorting zone, the product oil condensed, and a portion of the denuded gases recycled and returned to the retort vessel.

The next step in development was a change to complete countercurrent flow between descending shale and upward flowing recycle gas/combustion gases without the mid-retort withdrawal of combustion gases in the previous design. The recycle gas and air entered the bottom of the retort where the gases were preheated and almost immediately ignited, and passed upward through the combustion zone, retorting zone, and shale preheating zone.

Because the combustion zone was near the bottom of the retort, the spent shale was discharged at fairly high temperatures (288°C to 315°C, 550°F to 600°F) with subsequent loss of sensible heat. This suggested introducing the air for combustion higher in the retort, thus moving the combustion zone upward and increasing the depth of the gas preheating zone beneath. The result was the gas combustion concept (Figure 32). The concept was modified in later developments to include diluting the air with a portion of the recycle gas, in order to avoid severe clinkering in the vicinity of the air distributors (Figure 33).

Evaluation runs were made in the 51 cm (20 in) I.D., 5.4 tonnes/day (6 tons/day) pilot plant, under a variety of operating conditions, over a period of 5½ years. The unit served as a testing device for the larger retorts which followed.

A 22.7 tonnes/day (25 ton/day) rectangular gas combustion pilot unit was next constructed with inside dimensions of 71 cm by 122 cm (28 in by 48 in). This was later scaled-up to a 136 tonnes/day (150 tons/day) engineering-scale plant (Figure 34) using a rectangular, refractory-lined retort with an inside cross-section of 1.8 meters by 3.0 (6 ft by 10 ft). Mass flow rates of approximately 1470 kg/hr/sq meter (300 lbs/hr/sq ft) were attained in these larger retorts before the Bureau of Mines discontinued its 12 year experimental program at Anvil Points in 1956.

Between 1964 and 1967 a consortium of six petroleum companies* leased the Anvil Point facilities and continued development of the gas combustion concept. Between May 1964 and April 1965 investigations were conducted under "Stage I," using the 6 TPD and 25 TPD pilot units previously described. This was followed by completely rebuilding and operating the 150 TPD experimental retort during the "Stage II" period, April 1966 to September 1967.

Throughput rates of 327 tonnes/day (360 tons/day corresponding to mass flow rates of 2445 kg/hr/sq meter (500 lbs/hr/sq ft) cross-section were attained prior to completion of the experimental program. Shale oil yields were 83-87% of Fischer assay.

It was concluded that commercial scale-up of the modified gas combustion retort configuration, as tested by the consortium, would be "restricted within rather narrow (operating) limits." Specific difficulties were encountered with small shale sizes, high rates of gas and shale throughput, and bridging due to rich shales. As a result there are no present plans to scale-up the USBM modified gas combustion process, per se, to a commercial-size module. However, the Paraho/DEI version of the combustion retorting concept has been designed to overcome the above limitations and to be expanded to commercial size.

MODIFIED GAS COMBUSTION PROCESS

The description of the Gas Combustion Process given below is based upon the modifications developed at Anvil Points by the six company consortium during the period 1964 to 1967. The earlier designs of the U.S. Bureau of Mines have been published by Matzick, et al (Reference 1) (see list of References at the end of this report) and are not repeated here.

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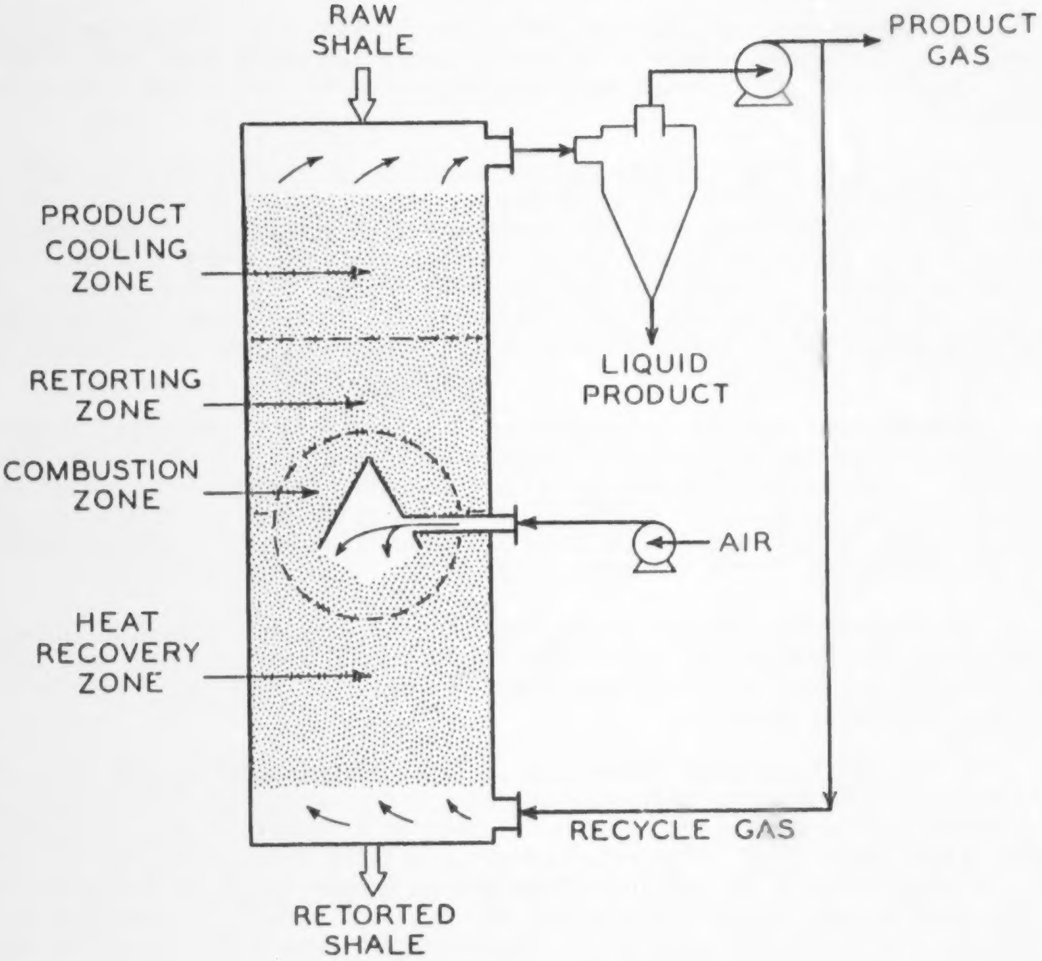
*Mobil, Humble, Pan American, Sinclair, Phillips, Continental


RAW SHALE
PRODUCT GAS
PRODUCT COOLING ZONE
LIQUID PRODUCT
RETORTING ZONE
COMBUSTION ZONE
AIR
HEAT RECOVERY ZONE
RECYCLE GAS
RETORTED SHALE

*from Cramer, R. H., et al, "Evaluation of Pilot Plant Results from Gas-Combustion Retorting of Oil Shale," preprint, AIME Meeting, Washington, D.C., February 19, 1969.

Figure 32. Conceptual Process Flow Diagram.*

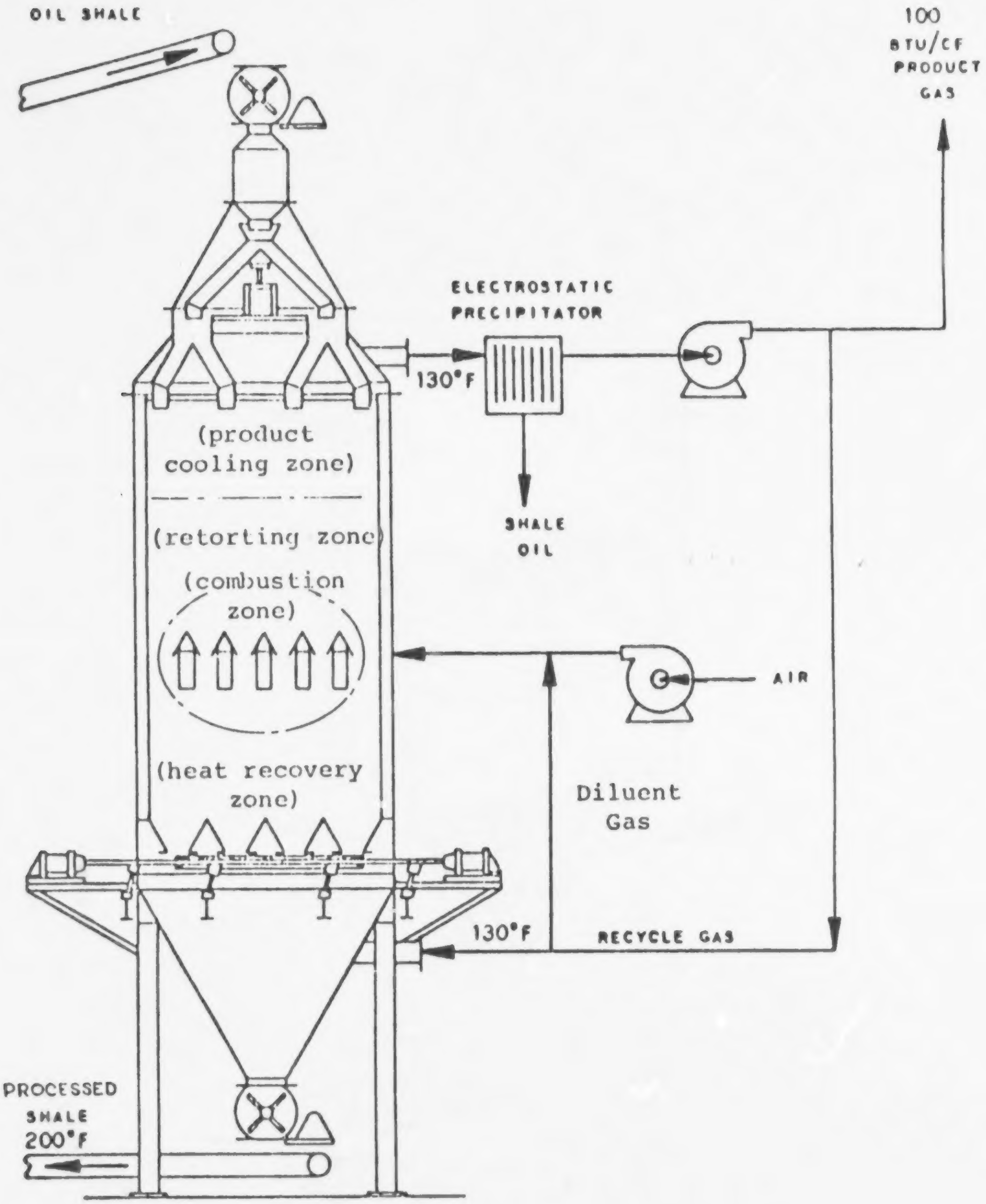
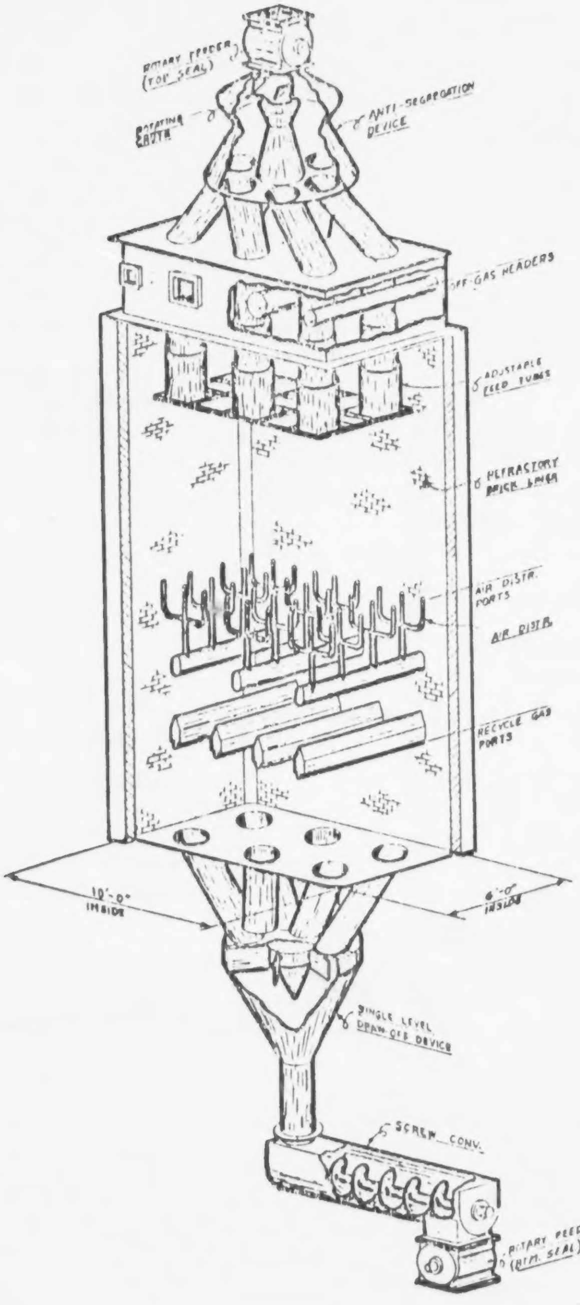

OIL SHALE
100
BTU/CF
PRODUCT
GAS
ELECTROSTATIC
PRECIPITATOR
130°F
(product
cooling zone)
SHALE
OIL
(retorting zone)
(combustion
zone)
AIR
(heat recovery
zone)
Diluent
Gas
130°F
RECYCLE GAS
PROCESSED
SHALE
200°F

Figure 33. Gas Combustion Retort.


ROTARY FEEDER (TOP SEAL)
ROTATING CHUTE
ANTI-SEGREGATION DEVICE
OFF-GAS HEADERS
ADJUSTABLE FEED TUBES
REFRACTORY BRICK LINER
AIR DISTR. PORTS
AIR DISTR.
RECYCLE GAS PORTS
10'-0" INSIDE
6'-0" INSIDE
SINGLE LEVEL DRAW-OFF DEVICE
SCREW CONV.
ROTARY FEEDER (BTM. SEAL)

*from Clampitt, R. L., et al, preprint,
161st Nat. Mtg. ACS, Los Angeles, March 29, 1971

Figure 34. USBM 150 ton/day Gas Combustion Retort.*

Underground Mining, Crushing

Initial mining operations by the consortium at Anvil Points utilized the USBM demonstration mine. Some 31,700 tonnes (35,000 tons) of shale were mined before it was determined that better safety and mining research conditions existed on a nearby Mobil oil shale property. A new experimental mine was accordingly opened and used for the duration of the research program.

Shale from the experimental mine at approximately 2440 meters (8000 ft) altitude was trucked to the processing area at an elevation of about 1,830 meters (6,000 ft). At the plant site the mined shale was crushed in the primary and secondary circuits of the USBM crushing plant and screened into various feed-size ranges for the 136 tonnes (150 ton/day) modified gas combustion retort. The 10-15% fines from screening were stockpiled.

Feed size range was one of the variables examined during the experimental program. The two longest demonstration runs were attained with shale feeds with a nominal range of 2.5 to 6.4 cm (1 to 2½ in) and 6 mm to 6.4 cm (¼ to 2½ in).

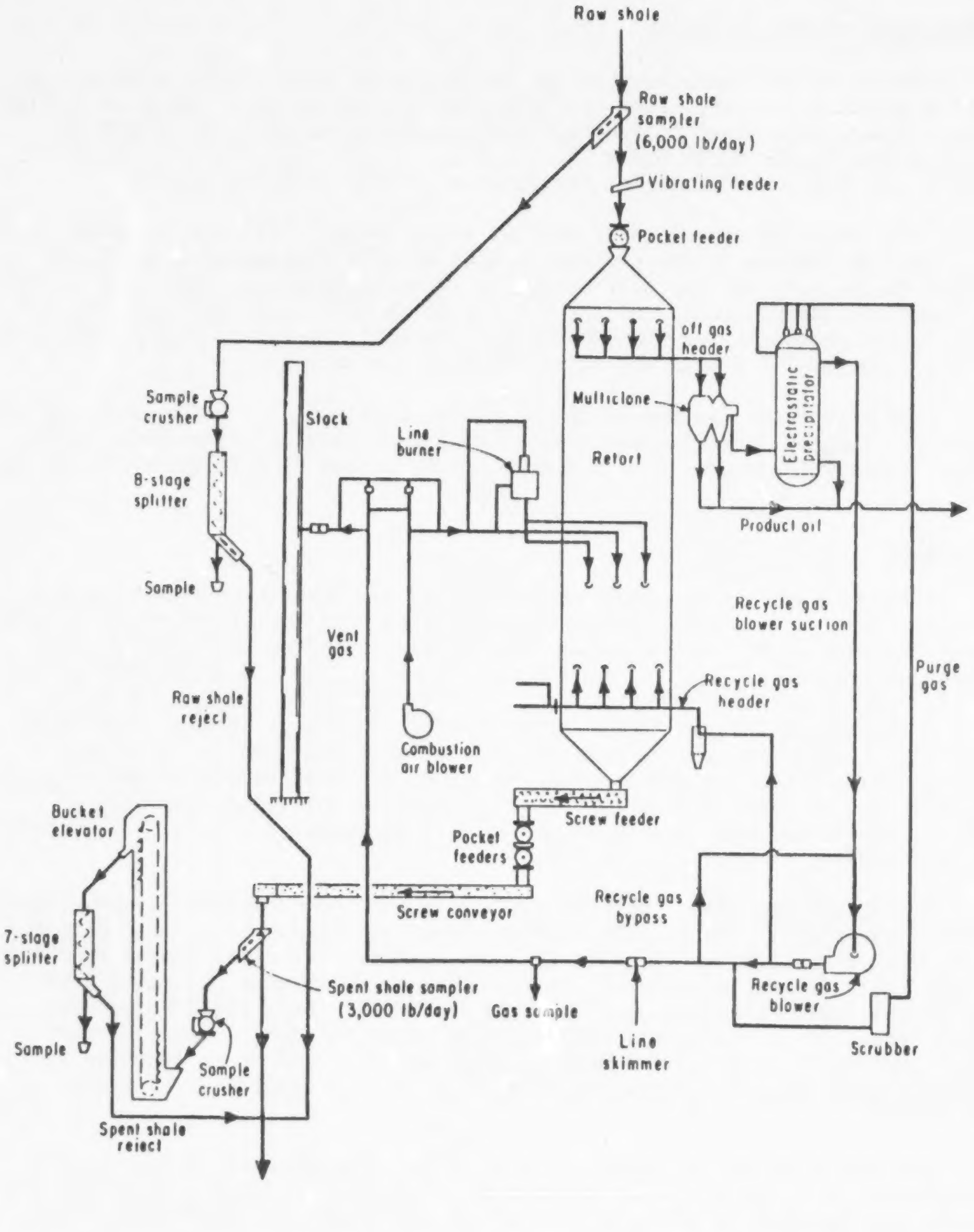
Retorting

A flow diagram of the modified 150 ton/day gas combustion retorting process is shown in Figure 35. The refractory-lined rectangular retort (Figure 34) was 1.8 meters (6 ft) by 3.0 meters (10 ft) cross-section, with a shale bed height of 1.1 meters (3.7 ft) to 4 meters (13 ft). The raw shale feed varied in richness from 97.8 liters/tonne to 130.6 liters/tonne (23.5 to 31.4 gal/ton). It entered the top of the retort in the usual way, through a rotating chute and passed downward through the conventional gas combustion product cooling zone, retorting zone, combustion zone, and heat recovery zone. The spent shale, at about 55°C (130°F), was discharged through a single-level drawoff device and sent to a disposal pile in an adjacent canyon. It contained 2-3% organic carbon.

During the operating phase of the consortium's experimental program mass shale flow rates in the 150 TPD retort were varied from 1247 to 2494 kg/hr/sq meter (255-510 lbs/hr/sq ft) retort cross-section. Air rates ranged from 121 to 255 cubic meters/tonne (3,880 to 8,200 ft^3/ton), recycle gas rates from 312 to 550 cubic meters/tonne (10,000 to 17,600 ft^3/ton), and dilution gas rates from 0 to 94 cubic meters/tonne (0 to 3,020 ft^3/ton). Some 132 runs were completed in the 150 TPD retort. Most were of 8-12 hours duration but several demonstration runs varied from 10 to 17 days total in 2 to 5 day increments.

The air distributor headers were oriented perpendicular to the recycle gas headers in order to reduce recycle gas channeling. It was found that the number and location of air injection points was a strictly empirical matter if clinker formation was to be avoided.

The oil recovery system was modified to include a multiclone separation unit for removal of large shale mist particles and an electrostatic precipitator for very small particle removal. The efficiencies of these separation


Raw shale
Raw shale sampler (6,000 lb/day)
Vibrating feeder
Pocket feeder
off gas header
Multiclone
Electrostatic precipitator
Sample crusher
Stack
Line burner
Retort
8-stage splitter
Product oil
Sample
Recycle gas blower suction
Vent gas
Purge gas
Raw shale reject
Recycle gas header
Combustion air blower
Bucket elevator
Screw feeder
Pocket feeders
Recycle gas bypass
Screw conveyor
7-stage splitter
Spent shale sampler (3,000 lb/day)
Gas sample
Recycle gas blower
Sample
Line skimmer
Scrubber
Sample crusher
Spent shale reject

*from USBM Rept. of Investigations #7540 (July 1971).

Figure 35. Flow Diagram of 150 TPD Modified Gas Combustion Retort and Auxiliaries*

units was a function of shale rate, shale particle size distribution, and retort gas rates. The product oil obtained was fed to a decant tank to separate the water of retorting. Total water yields varied between approximately 25 and 45 kg/tonne (50 and 90 lbs/ton) of shale processed, from shale of 104 to 125 liters/tonne (25 to 30 gal/ton) richness. Oil yields were in the range of 82.5 to 86.6% of Fischer assay.

Demonstration Runs

Included in the 1966-67 operation of the 150 TPD modified gas combustion retort by the six company consortium were two demonstration runs. The first of these, using 2.5 cm to 6.4 cm (1 in to 2½ in) raw shale, was of 10 days duration divided into two five-day increments, each with somewhat different operating conditions. The parameters for one of these 5-day runs is shown in Table 7. Also shown in Table 7 are parameters for one of the five-day increments from a 17-day demonstration run which used a 6 mm to 6.4 cm (¼ in to 2½ in) shale feed.

Table 7. Selected Demonstration Run Results Modified Gas Combustion Process*

Item	Shale Feed Size, inches	
	1 to 2.5	0.25 to 2.5
Raw Shale, GPT	25.5	29.4
Operating Conditions		
Shale Feed Rate, lbs/hr/ft^2	400	301
Air Rate, SCF/ton	4,600	4,250
Recycle Rate, SCF/ton	14,500	13,200
Retorted Shale Temp., ^{o}F	374	496
Products Recovered		
Oil Yield, vol % Fischer Assay	86.6	85.6
Oil Gravity, ° API	20.1	20.5
Total Water Yield, lbs/ton	76	55.2
Dry Gas Yield, SCF/ton	6,050	5,800
Dry Gas Heating Value, Btu/SCF	ca 100	ca 100
Avg. Spent Shale Organic Carbon, %	2.1	2.5
Mineral Carbonate Decomposed, %	38.2	23.8
Duration of Operating Conditions, days	5	5
Total Duration of Run, days	10	17

*Adapted from Clampitt, R. L., et al, "Gas Combustion Retorting Performance in a Large Demonstration Retort," 161st National Meeting ACS, Los Angeles, March 29, 1971.

It is noted from the table that the API gravity and yields of shale oil were essentially the same in the two cases even though the mass throughput rate of the finer shale was less. The residual organic carbon on the spent shale from the +¼" to 2½" feed was somewhat higher. This could reflect a higher retorting temperature and the higher spent shale discharge temperature noted, except for the fact that mineral carbonate decomposition was substantially lower for the finer shale run. It is felt that the high shale discharge temperatures and the large mineral carbonate decompositions noted would both have to be considerably less than shown, for any practical commercial retort, in order to increase process heat economy.

Retort water yields, 2.8 to 3.8% of shale feed (equivalent to 27.5-37.8 liters/tonne or 6.6-9.1 gals/ton), are in the usual range previously reported for USBM gas combustion retorting. The analysis of these waters was not measured nor was the plant air emissions.

It was concluded from the consortium's experimental test program that "substantial modifications to the (gas combustion) process would probably have to be developed and tested in order to extend the operating range and yields much beyond those demonstrated," and that this would require considerable further prototype-size testing before scale-up to a commercial module.

ENVIRONMENTAL IMPACTS

All pilot plant research and demonstration programs carried out on the USBM Gas Combustion process were completed by September 1967, more than two years before the National Environmental Policy Act of 1969 or the subsequent Clean Water and Clean Air legislation. It is therefore not surprising that little or no data are available from these programs on spent shale characteristics or disposal methods, air emissions, liquid effluents, or other environmental impact factors. Any assessments of the process in this regard must be based on extrapolations from other (similar) retorting methods, or theoretically computed.

The Paraho direct-mode process is a variation of the USBM Gas Combustion process, and hence the most similar to the latter. It is to be noted, however, that the Paraho process is, itself, still under development and that environmental data are still limited since they are presently still being determined. Some conclusions as to gas combustion process environmental characteristics are possible, however, by analogy with Paraho direct-mode retorting.

Retorted Shale

It is noted in Table 7 that organic carbon on the gas combustion (GC) retorted shale varies from about 2 to 2.5% which is similar to the 2% carbonaceous residue on the Paraho shale. The GC retorted shale might therefore be expected to have the same disposal characteristics as Paraho shale. Among these are:

(1) Size range essentially unchanged from raw shale feed distribution.

(2) Compaction to from 1410 to 1570 kg/cu meter (88 to 98 lbs/cu ft) density in a disposal pile, with 22-23% moisture

(3) Soluble salts content in the order of 2% with a pH of approximately 8.8 to 11.0 and electrical conductivities of 5-20 mmhos.

(4) Surface layers of disposal piles should be leached prior to revegetation.

Retort Gases

The GC retort gases have heating values in the order of 890 kcal/std cu meter (100 Btu/SCF). On a dry basis they contain from 22-25% CO_2, 61-63% N_2, 2-3% CO, and 2-5% H_2. The hydrogen sulfide and ammonia contents have not usually been measured† but can be expected to be similar to those for Paraho direct mode retort gases, which are reported in one case to be 2660 ppm H_2S and 2490 ppm NH_3. The sulfur (and ammonia) in the product gases would require reduction prior to combustion as a plant fuel.

Retort Water

An analysis of the retort water separated from GC shale oil has been reported in the literature, as shown in Table 8. It is noted that ammonia contents are 12.4 g/l (vs. 4.9 g/l for Paraho retort water), chloride is 5.4 g/l (Paraho: 5.3) and total nitrogen is 10.2 g/l (Paraho: 4.6). The pH of 8.8 is similar to that for Paraho water (7.6). The GC water will probably be used to moisten the spent shale disposal pile.

Table 8. Analysis of Gas Combustion Retort Water*

Components	Concentration (grams/liter)
Ammonia	12.4
Sodium	1.0
Carbonate	14.4
Total Carbon	18.5
Chloride	5.4
Nitrate	Trace
Total Nitrogen	10.2
Sulfate	3.1
Sulfur, non-sulfate	1.9
pH	8.8

*From Synthetic Fuels Data Handbook, Cameron Engineers, Denver, 1975, p 101.

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†There is one literature value of 1000 ppm H_2S from unpublished USBM data.

Shale Oil

A typical analysis of the shale oil obtained by the consortium from the modified Gas Combustion retort is shown in Table 9. It is noted that the properties are similar to those for conventional shale oils from internally-heated retorts involving direct combustion for heating. A typical direct-mode Paraho shale oil, for example, has a pour point of 29°C (85°F), vs. 80°F for GC oil and an API gravity of 21.4°, vs. 19.7 for GC oil.

Table 9. Properties of Shale Oil from Modified Gas Combustion Retort (dry basis)

API Gravity, °	19.7
Pour Point, °F	80
Viscosity, SUS, 100°F	256
Sulfur, wt %	0.74
Nitrogen, wt %	2.18
Carbon Residue, wt % (calc'd from residuum)	4.5

*From Ruark, J. R., et al, USBM Rept. of Investigation #7540 (1971).

50,000 BPD COMMERCIAL PLANT

Katell and Wellman (Reference 5) have presented economic analyses of several commercial-scale oil shale plants utilizing the Gas Combustion Process. The study must be considered of a preliminary nature since it is evident from the previous sections of this report that additional research and development will be required in mining, processing, and environmental controls technology before the reliability of such extrapolations is insured. However, the order-of-magnitude results are of interest.

Some highlights of this study are presented below for a plant producing 7,940 cubic meters/calendar day (50,000 BPD) of partially refined (hydrofined) shale oil, from 71,290 tonnes/day (78,600 tons/day) of raw shale with a richness of 125 liters/tonne (30 GPT). Included in the technology are an activated carbon unit for removal of H_2S and a slurry system for spent shale disposal, neither of which has ever been tested in actual operation. The economic data are in mid-1973 dollars and hence require considerable escalation to reflect present-day costs, selling prices, etc.

The plant is estimated to produce, in addition to shale oil, per calendar day some 116 tonnes (128 tons) of sulfur, 125 tonnes (138 tons) of ammonia, and 775 tonnes (855 tons) of by-product coke. Six Gas Combustion retorts are projected, each 17 meters (56 ft) in diameter with a shale bed depth of 5.5 meters (18 ft). Each retort has a throughput of 13,060 tonnes (14,400 tons) per stream day of raw shale, and produces 1,540 cubic meters (9,700 barrels) per day of crude shale oil, 10,160 tonnes (11,200 tons) per day of spent shale, and 2.45 million standard cubic meters per day (86.2 million SCF/day) of excess low Btu gas. It is estimated that 60-70% of the spent shale would be disposed of in the underground mine, and the remainder on the surface.

The capital investment* for the mine, retort plant, refinery, and associated facilities were estimated to be nearly $230 million. Catalyst and chemicals inventory, interest during construction and start-up, plus working capital increased the total capital investment to $280 million. Annual operating costs were calculated to be $63 million (before a by-product credit of $4 million is taken). The unit cost of shale oil, before by-product credit, was thus estimated to be $21.60 cubic meter ($3.45/bbl). A selling price of $35.50 cubic meter ($5.65/bbl) was projected, based upon 12% discounted cash flow and a 20-year plant life.

It is obvious that the above costs and selling price are now obsolete, based upon present economics.

REFERENCES

The development of the gas combustion process by the U.S. Bureau of Mines, and later the six-company consortium directed by Mobil Oil, is documented in the following pertinent literature references:

1. Matzick, A., et al, "Development of the Bureau of Mines Gas-Combustion Oil-Shale Retorting Process," U.S. Bureau of Mines Bulletin 635 (1966).

2. Ruark, J. R., Sohns, H. W., Carpenter, H. C., "Gas Combustion Retorting of Oil Shale Under Anvil Points Lease Agreement: Stage I," USBM Report of Investigation 7303 (1969); Stage II, ibid USBM Report of Investigation 7540 (1971).

3. Clampitt, R. L., et al, "Gas Combustion Retorting Performance in a Large Demonstration Retort," preprint, 161st National Mtg., American Chemical Society, Los Angeles (March 29, 1971).

4. Katell, S. and Wellman, P., "Mining and Conversion of Oil Shale in a Gas Combustion Retort," USBM Technical Progress Report, TPR 44,(October 1971).

5. Katell, S. and Wellman, P., "An Economic Analysis of Oil Shale Operations Featuring Gas Combustion Retorting," USBM Technical Progress Report, TPR 81, (September 1974).

6. Katell, S., Stone, R., Wellman, P., Oil Shale - A Clean Energy Source, Colorado School of Mines Quarterly, Vol. 69, No. 2, 1-19 (April 1974).

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*All dollars are mid-1973 dollars, and costs are at mid-1973 rates.

OCCIDENTAL MODIFIED IN-SITU PROCESS

C. C. Shih

Occidental Petroleum Corporation's involvement in oil shale technology is a relatively recent development. In late 1972, Garrett Research and Development Company (now Occidental Research and Development), a subsidiary of Occidental Petroleum Corporation, announced plans for the field testing of a modified in-situ shale oil recovery scheme which is the subject of U.S. Patent 3,661,423. The actual work began in the summer of 1972 on the D.A. Shale property at the head of Logan Wash, outside of Debeque, Colorado (Figure 36). In the ensuing months, three research retorts, each 9.1 m (30 ft) on a side and 21.9 m (72 ft) high, were prepared and ignited. At the end of 1974 the project was transferred to an operating branch of the company, when Occidental Oil Shale, Inc., a subsidiary of the Occidental Oil and Gas Production Division, was set up. Concurrently, a decision was made to initiate the development of a commercial size retort in the commercial mine, located in a canyon off the north side of Logan Wash about a quarter mile below the head. The commercial mine is being developed at a new location because there is insufficient room at the head of Logan Wash (the research mine location) to permit a large mining operation, and because the research mine is located just below the Mahogany Ledge and too high for the construction of commercial size retort columns. The first commercial size retort (Retort No. 4), with a 36.6 m (120 ft) by 36.6 m (120 ft) cross section and 76.2 m (250 ft) height and containing 15 gpt rubblized shale, was ignited from the top on December 10, 1975. The burn was continued successfully until late June 1976 with a total production of 27,500 barrels of crude shale oil. Sustained combustion and temperature control was achieved by recycle of a portion of the retort gas. A second commercial size retort (Retort No. 5) similar in dimensions to Retort No. 4 was then also prepared.

MINING AND FRACTURING

The modified in-situ process for shale oil recovery consists of retorting a rubblized column of broken shale, formed by expansion of the oil shale into a previously mined out void volume. The Occidental process involves three basic steps. The first step is the mining out of approximately 20 to 25% of the oil shale deposits (preferably low grade shale or barren rock), either at the upper and/or lower level of the shale layer. This is followed by the drilling of vertical longholes from the mined-out room into the shale layer, loading these holes with an ammonium nitrate-fuel oil (ANFO) explosive, and detonating it with appropriate time delays so that the broken shale will fill both the volume of the room and the volume of the shale column after blasting. Finally, connections are made to both the top and bottom and retorting is carried out (Figure 37).

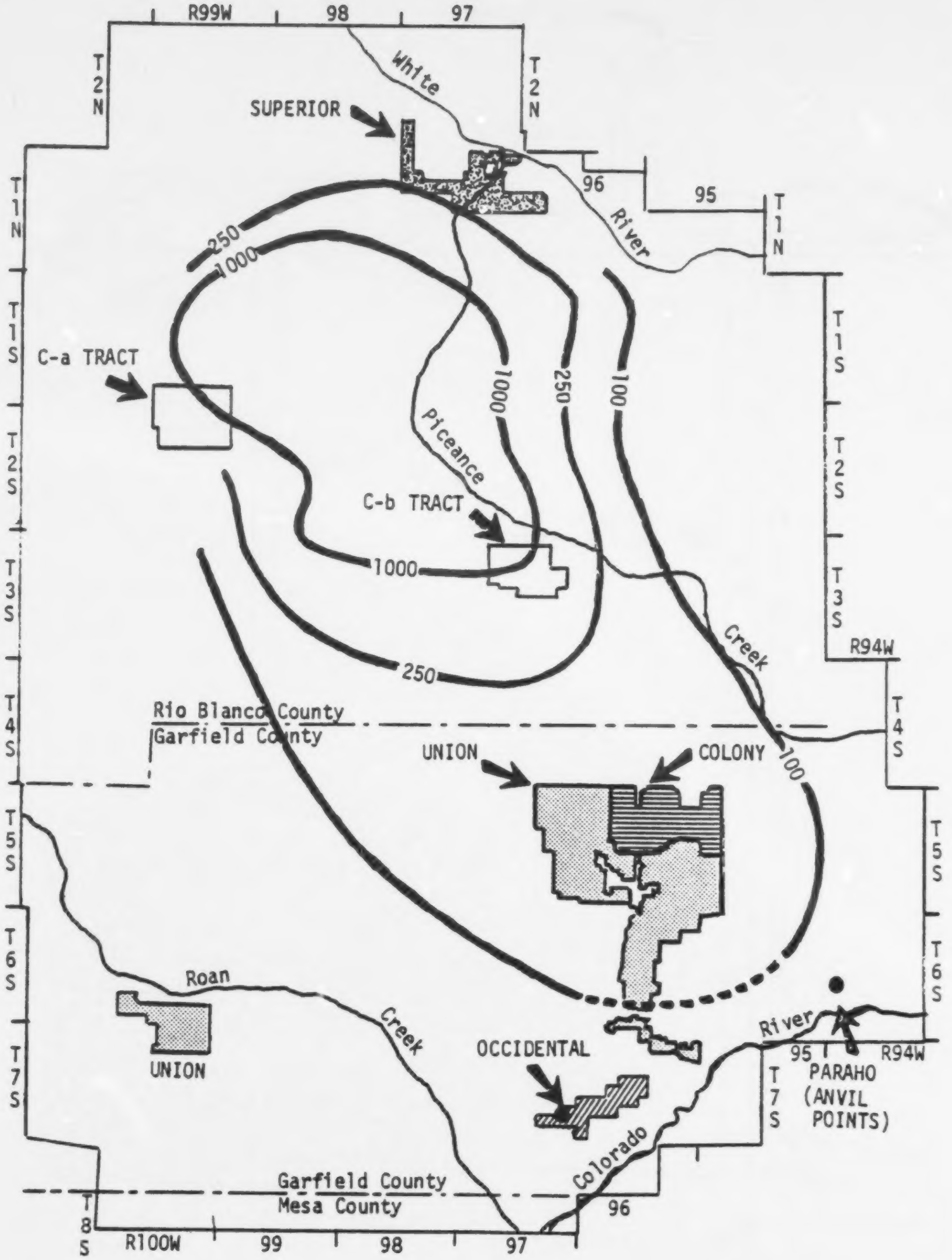

R99W
98
97
T 2 N
White
SUPERIOR
T 2 N
96
95
River
T 1 N
T 1 N
250
1000
T 1 S
C-a TRACT
1000
250
100
T 1 S
Piceance
T 2 S
T 2 S
C-b TRACT
T 3 S
1000
T 3 S
Creek
R94W
250
T 4 S
Rio Blanco County
Garfield County
UNION
COLONY
100
T 4 S
T 5 S
T 5 S
T 6 S
Roan
T 6 S
Creek
River
UNION
OCCIDENTAL
95
R94W
T 7 S
T 7 S
PARAHO (ANVIL POINTS)
Colorado
Garfield County
Mesa County
96
T 8 S
R100W
99
98
97

Figure 36. Occidental Oil Shale Lease Property in Piceance Creek Basin, Colorado

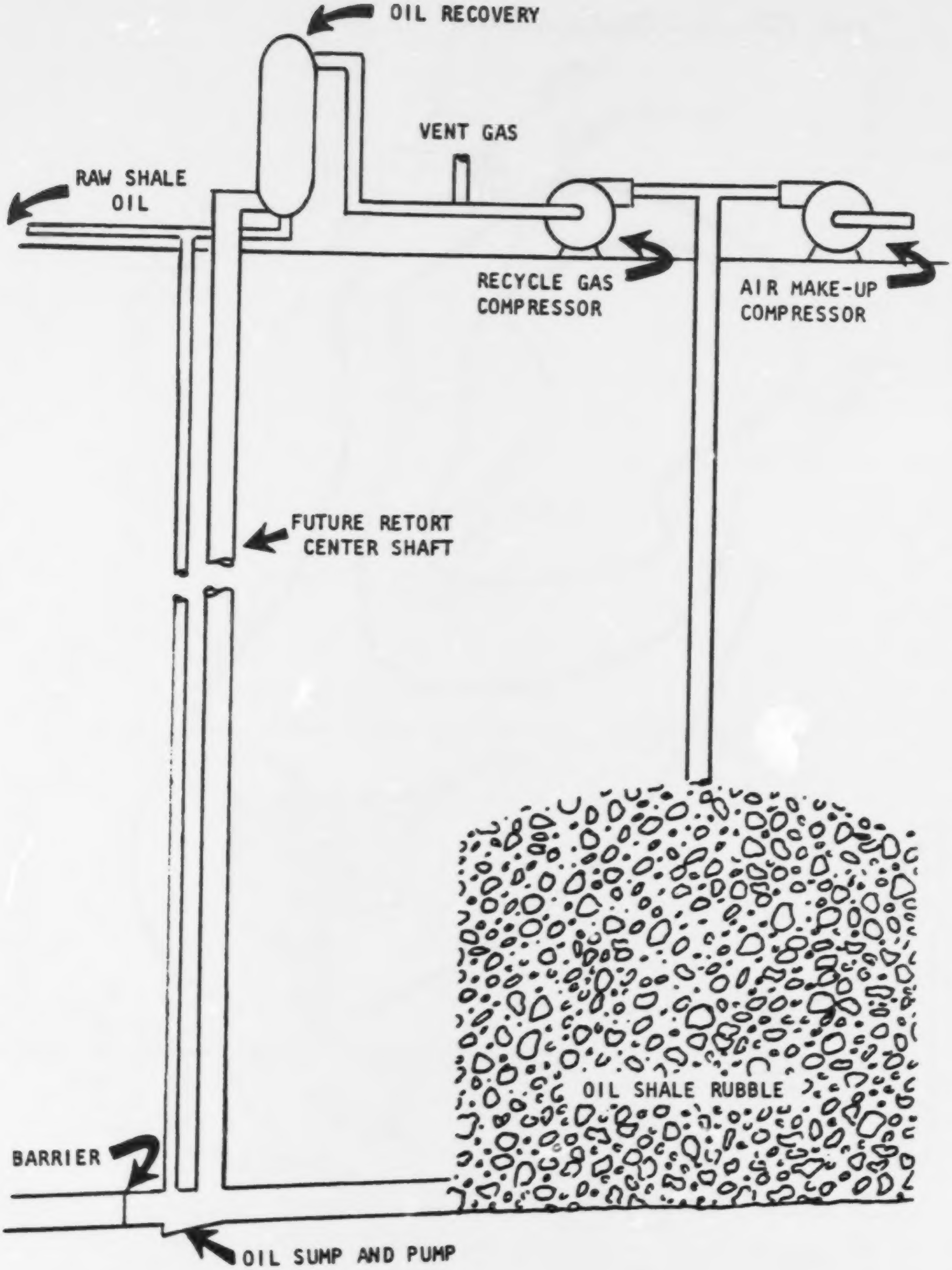

OIL RECOVERY
VENT GAS
RAW SHALE OIL
RECYCLE GAS COMPRESSOR
AIR MAKE-UP COMPRESSOR
FUTURE RETORT CENTER SHAFT
OIL SHALE RUBBLE
BARRIER
OIL SUMP AND PUMP

Figure 37. Retorting Operation of the Occidental Modified In-Situ Process.

A plan view of a typical commercial development based on the Occidental scheme is presented in Figure 38. The commercial size rooms would be 36.6 to 48.8 m (120 ft to 160 ft) square with a height determined by the height of the oil shale zone. The thickness of the walls between adjacent retorts depends on whether the rubblized chimney will be a totally load supporting mass by itself or whether the walls are required to serve as actual pillar supports. In the former case, a wall thickness of 20 feet is probably adequate since the walls only serve to physically separate the retorting chambers from one another. In the latter case, however, the dimensions of the walls will be significantly greater.

Both the size of the retorting chamber and the thickness of the walls have an important impact on the fraction of the cross section of the shale formation available for retorting. With 40 feet thick walls, the cross section of the shale formation available for retorting would be 56% for 36.6 m (120 ft) square retorting chambers and 64% for 48.8 m (160 ft) square retorting chambers. With 20 feet thick walls, the cross section of the shale formation available for retorting would be 73% for 36.6 m (120 ft) square retorting chambers and 79% for 48.8 m (160 ft) square retorting chambers. Thus large retorting chambers and thin walls are necessary for the optimum recovery of oil shale resources.

Assuming that 20% of the rock is mined out to create the void volume necessary for subsequent rubblization, a 36.6 m x 36.6 m x 76.2 m (120 ft x 120 ft x 250 ft) commercial size retort could yield 8,042 m^3 (50,584 barrels) of crude shale oil, at 65% retorting efficiency and for 15 gpt shale. The results from the Occidental experiments indicated a retort burn rate of 1.372 cm/hr (0.54 in/hr), thus the production period of a 76.2 m (250 ft) high retort is 232 days and the production rate of crude shale oil from a commercial size retort is 34.74 m^3/day (218.5 BPD). As shown in Table 10, 229 retorts would be required to operate simultaneously to produce 7,950 m^3/day (50,000 BPD) of crude shale oil if the average Fischer assay of the shale zone is 15 gpt. For a shale zone with an average Fischer assay of 25 gpt, a minimum of 149 retorts would still be required if the production goal of 7,950 m^3/day (50,000 BPD) of crude shale oil were to be realized (Table 10).

In the construction of the commercial size retort, Occidental plans minming at two levels (Figure 39). The upper mining level will be a complete heading at or near the top of the retort, and will serve as a base from which vertical longholes will be drilled for the loading of explosives. In the retorting process, combustion air will be supplied through the heading.

Note: Figures 37 and 40 are obtained from the paper "Development of the Modified In-Situ Oil Shale Process" by H. E. McCarthy and C. Y. Cha, presented at the 68th AIChE Annual Meeting, Nov. 16-20, 1975, Los Angeles, California. Figures 38 and 39 are obtained from the Synthetic Fuels Quarterly Reports published by Cameron Engineers, Inc., June 1974 and June 1975, respectively.

PLAN VIEW

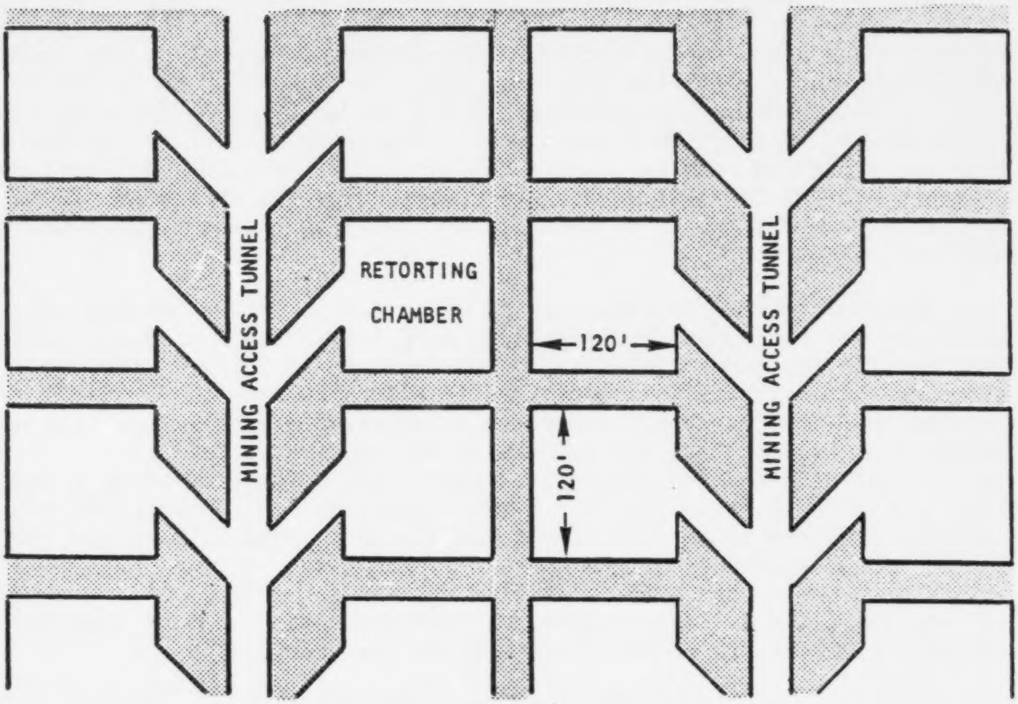
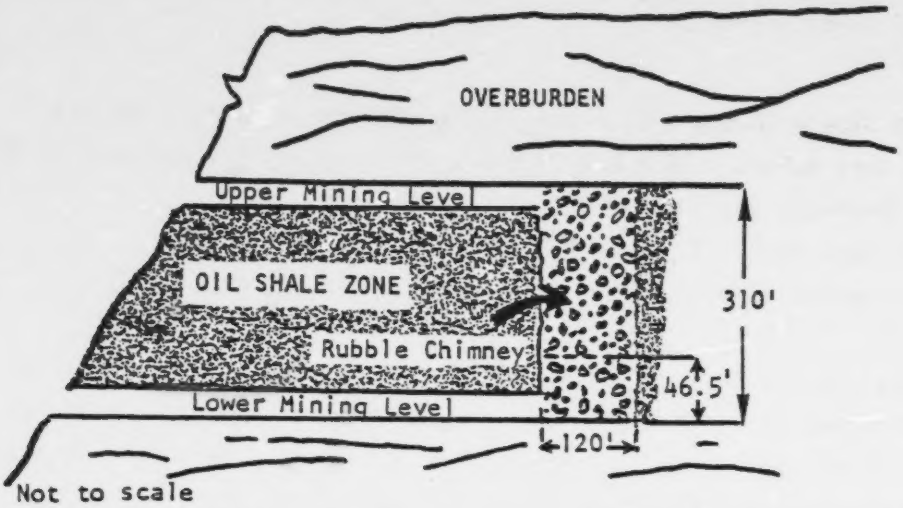
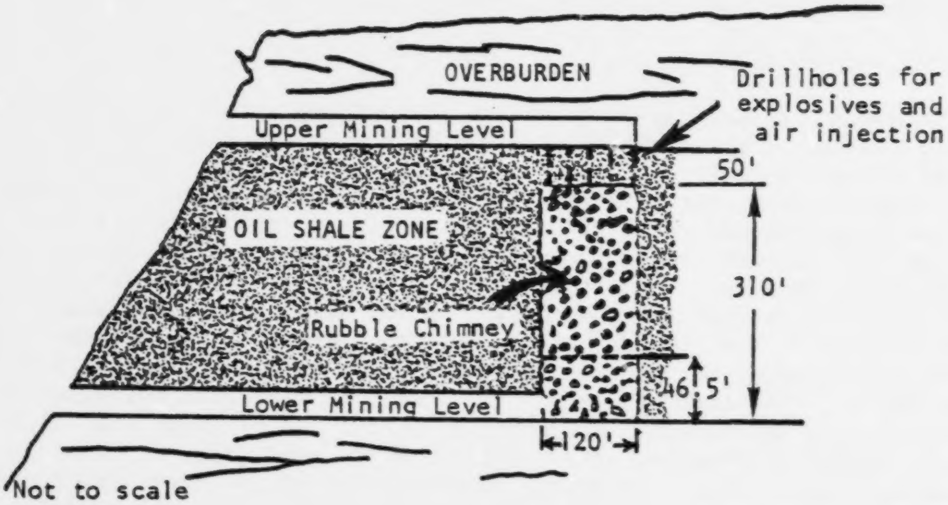

MINING ACCESS TUNNEL
RETORTING CHAMBER
120'
120'
MINING ACCESS TUNNEL

Figure 38. Occidental's Proposed Commercial Scale In-Situ Mining Scheme.


OVERBURDEN
Upper Mining Level
OIL SHALE ZONE
Rubble Chimney
310'
46.5'
Lower Mining Level
120'
Not to scale

Scheme No. 1: No vertical separation


OVERBURDEN
Drillholes for explosives and air injection
Upper Mining Level
50'
OIL SHALE ZONE
Rubble Chimney
310'
46.5'
Lower Mining Level
120'
Not to scale

Scheme No. 2: 50' vertical separation

Figure 39. Two Level Mining for Commercial Size Retort.

Table 10. Commercial Production of Shale Oil Based on Occidental Modified In-Situ Process

Basis:

Retort Size = 36.6 m x 36.6 m x 76.2 m (120 ft x 120 ft x 250 ft)

Mined Void Volume = 36.6 m x 36.6 m x 15.2 m (120 ft x 120 ft x 50 ft)

Wall Thickness = 6.1 m (20 ft)

Retort Burn Rate = 1.372 cm/hr (0.54 in/hr)

Total Commercial Production = 7,950 m^3/day (50,000 BPD)

Average Fischer Assay of Shale (gpt)	15	20	25
Specific Gravity of Shale*	2.425	2.330	2.245
Quantity of Shale Mined (tonnes/day)	51,424	38,568	30,854
Oil Production Per Retort (m^3/day)	34.74	44.51	53.61
No. of Retorts Required	229	179	149
Area Affected by Retorting (m^2)	417,000	326,000	271,300

*Average specific gravity of oil shale samples from Anvil Points area. Synthetic Fuels Data Handbook, Cameron Engineers, Inc., 1975, p 10.

RETORTING AND UPGRADING

In the Occidental modified in-situ process, retorting is initiated by heating the top of the rubblized shale column with the flame formed from compressed air and an external heat source, such as propane or natural gas. After several hours, the external heat source is removed and the compressed air flow is maintained, utilizing the carbonaceous residue in the retorted shale as fuel to sustain air combustion. In this vertical retorting process, the hot gases from the combustion zone move downwards to pyrolyze the kerogen in the shale below that zone, producing gases, water vapor, and shale oil mist which condense in the trenches at the bottom of the rubblized column (Figure 40). The oil production precedes the advancing combustion front by 9 to 12 m (30 to 40 ft). The crude shale oil and byproduct water are collected in a sump and pumped to storage. The off-gas is composed of gases from shale pyrolysis, carbon dioxide and water vapor from the combustion of carbonaceous residue and carbon dioxide from the decomposition of inorganic carbonate (primarily dolomite and calcite). Part of this off-gas is recirculated to control the oxygen level in the incoming air and the retorting temperature. The off-gas has a heating value of approximately 2.56 MJ/Nm^3 (65 Btu/SCF), and the part of the off-gas not recycled will be burned in a turbine for electric power generation after hydrogen sulfide removal by the Stretford process. Occidental has indicated that turbines manufactured by Brown-Boveri of Switzerland will be investigated for this application.

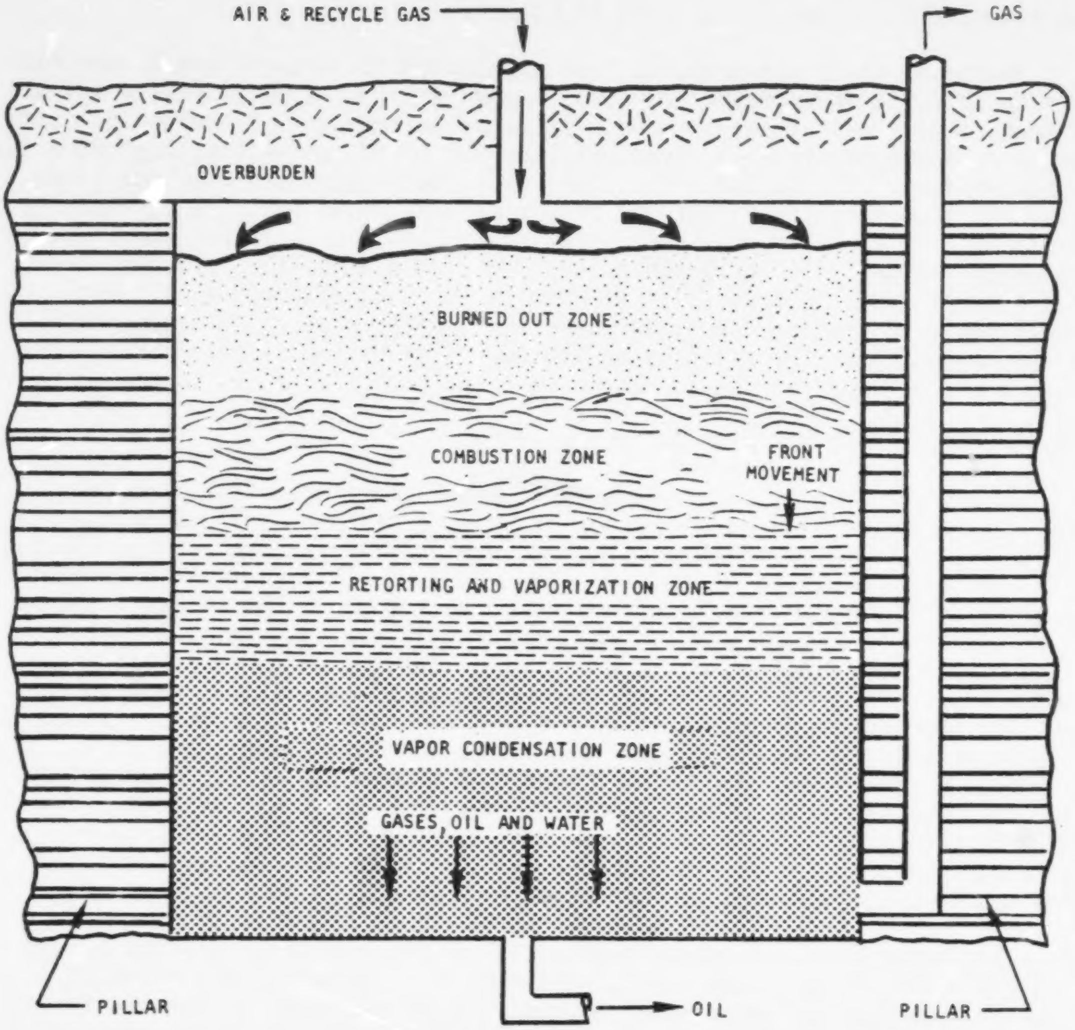

AIR & RECYCLE GAS
GAS
OVERBURDEN
BURNED OUT ZONE
COMBUSTION ZONE
FRONT MOVEMENT
RETORTING AND VAPORIZATION ZONE
VAPOR CONDENSATION ZONE
GASES, OIL AND WATER
PILLAR
OIL
PILLAR

Figure 40. Flame Front Movement in the Occidental Modified In-Situ Process

According to Occidental's estimate, only 20 to 25% of the electric power produced from the low-Btu gas is required for operating the modified in-situ process. Occidental has not disclosed any information on the design of a surface oil and gas treatment plant. The minimum treatment required for the crude shale oil produced from the retorting process will include phase separation of the oil from the byproduct water and the stabilization of the oil product. The waste-water effluent from the phase separator may be used for steam generation after appropriate treatment.

The crude shale oil produced from the Occidental process has a specific gravity of 0.904 (API gravity of 25^{o}), a pour point of $21^{o}C$ ($70^{o}F$), a sulfur content of 0.71 weight percent and a nitrogen content of 1.50 weight percent. The crude shale oil is also reportedly free of solids and may be used directly as boiler fuel. Occidental has claimed that tests conducted with the crude shale oil show that its direct use as boiler fuel would meet the current NO_x standards. This implies that less than 20% of the fuel nitrogen contained in the crude shale oil is converted to NO_x during the combustion process. For most other fuels, the conversion of chemically bound nitrogen to NO_x under normal boiler operating conditions is significantly higher and amounts to 50%. At the present time the validity of the NO_x tests with Occidental in-situ crude shale oil must be considered to be questionable.

ENVIRONMENTAL STUDIES AND ACTIVITIES

During the in-situ experiments, Occidental contracted Claremont Engineering to conduct ambient monitoring of gaseous criteria pollutants and stack monitoring of selected pollutants in the retort off-gas, such as SO_2, CO, and H_2S. The daily averages of the measured values of the pollutants have been reported to the State of Colorado on a quarterly basis. The retort off-gas is of special concern because of the large quantity of gas involved which eventually must be vented to the atmosphere after burning in a turbine to generate electric power or through simple incineration. The economic practicability of removing hydrogen sulfide from the retort off-gas prior to combustion, especially if electric power generation with the low-Btu gas proves to be infeasible, remains to be ascertained. In a previous study conducted by TRW, the quantity of vent gas released to the atmosphere was estimated to be $625Nm^3$/sec (1,400,000 SCFM) or 856 m^3/sec (1,810,000 ACFM) at 95°C (200° F), and comparable in magnitude and composition with the stack gas emitted from a 500 MW oil-fired electric power plant.

The volume of retort water produced from the Occidental process is approximately 1 m^3 per m^3 of shale oil. This quantity of water is similar to in-situ shale processing water requirements. It is not known whether Occidental has investigated the treatment of the retort water for use in oil shale development.

A second water problem of concern is the contamination of naturally occuring groundwater intercepted in the underground development of an oil shale zone. At Occidental's present site, there is little or no water flow (less than 2.3 m^3/hr or 10 gpm) due to the geology of the area. At the center of the basin, however, Occidental indicates that mining schemes will be designed to keep the aquifers isolated from the target oil shale zone below, and that cement linings of the shafts will allow access to the oil shale zone through the aquifers. In areas where there is a saline water below and within the target oil shale zone, Occidental believes that in most cases, it is possible to either seal off the area or to pump the water to the surface and reinject it in the same formation downdip. A closely related area of concern, the potential for underground leaching of the spent shale, is not considered by Occidental to be a significant problem. Occidental envisions that leaching of the retorted shale will be severely limited due to the large size of the shale pieces, and the movement of the water will be slow and probably be confined to the spent chimneys. The water quality in Roan Creek, Logan Wash and Dry Gulch is currently monitored by Occidental.

The rock that is mined will be dumped into the canyons near the oil shale mine. A permit for increase in mined waste disposal pile from 382,000 m^3 (500,000 cubic yards) to 6,500,000 m^3 (8.5 million cubic yards) was granted to Occidental by Garfield County Commissioners on January 12, 1976. The approval of this special permit provides Occidental with sufficient mined rock (low grade shale) disposal capacity to expand into the large demonstration phase. The permit was granted on the basis that the raw shale pile would not be found to degrade the water quality of the area. A second stipulation of the permit is that upon completion of the raw shale pile, Occidental will restore the vegetative cover to a condition similar and compatible with comparable natural talus slopes in the vicinity.

Occidental has developed a list of 48 activities for which environmental effects and permits must be considered, and has assembled a team of seven people to gather environmental baseline data. The environmental studies conducted include a meteorological study, fauna and flora studies, completed paleontological and archaeological studies, ambient air and retort vent gas monitoring studies, water quality monitoring studies, and others. The EIA for the Occidental pipeline planwas scheduled to be released in December 1976.

OIL SHALE RETORTING PRODUCTS AND UTILITIES REQUIREMENTS

For a commercial size development with 229 retorts operating simultaneously, each 36.6 m x 36.6 m x 76.2 m (120 ft x 120 ft x 250 ft) and containing oil shale with an average Fischer assay of 15 gpt, the Occidental modified in-situ process will generate the following products:

Shale Oil: 7,950 m^3 (50,000 bbl) per calendar day

Sulfur: 373 tonnes (411 tons) per calendar day

Mined Rock: 51,424 tonnes (56,685 tons) per calendar day

Wastewater: 331 m^3/hr (1,458 gpm)

The quantity of sulfur produced is estimated by assuming that the raw shale contains 0.2 weight % organic sulfur, and that all the organic sulfur not found in the crude shale oil (0.71 weight % sulfur) is collected in the Stretford process when hydrogen sulfide is removed from the retort off-gas.

The total water consumption rate for the Occidental operation is estimated to be 1 m^3 per m^3 of crude shale oil produced, or 331 m^3/hr (1,458 gpm), including dust control and site irrigation. The power required for the operation of the Occidental process is only 20 to 25% of the electric power produced from the retort off-gas, if power generation by the burning of the low-Btu gas in a turbine proves to be feasible. The fuel requirements for the process will be supplied by the combustion of the carbonaceous residue left in the retorted shale.

LETC/DOE IN-SITU OIL SHALE RESEARCH PROGRAM

C. H. Prien

The Laramie Petroleum Research Center, U.S. Bureau of Mines initiated research on liquid fuels from oil shale as a result of the Synthetic Fuels Act of 1944. For 15 years this research was primarily concerned with oil shale physical and chemical characteristics, and the properties of the shale oil resulting from surface retorting processes.

In 1959 some R&D effort was introduced on in-situ shale oil recovery. The in-situ investigations became a primary objective of the Center's oil shale research, beginning in 1965, and continued as a principal activity when these laboratories became the Laramie Energy Research Center of the Energy Research and Development Administration (LERC/ERDA) in 1975. This Center is now the Laramie Energy Technology Center of the Department of Energy (LETC/DOE).

In March 1975 a federal Interagency Oil Shale Planning Panel of experts in various oil shale disciplines issued a report on "Accelerated Oil Shale In-Situ Research - A National Program." This study has formed the basis for subsequent federal in-situ research planning in the agencies involved, including (LETC/DOE). It is the purpose of this present overview report to more fully describe the past and present in-situ oil shale research program at the Laramie Energy Technology Center,* and its anticipated goals for the near future.

BACKGROUND

In-situ processing of oil shale was probably first attempted in the mid-1940's by the Estonians, who ignited a bed of Baltic Kukersite oil shale in place, and removed the distillation products by suitably located take-off mains. During the same period (1944) the Swedes began operation of the Ljungstrom method, which heated an underground shale bed at Kvarntorp by means of electrical resistance heaters. These investigations were discontinued in the early 1950's.

During World War II underground pyrolysis of the Wurttemburg shales of Germany was attempted on a semi-works basis, partially with German Navy support. A modified in-situ horizontal retorting process involving first rubblizing the shale in place was employed. Yields were poor however, seldom exceeding 30% of Fischer assay.

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*In addition to the LERC/DOE programs described in this report, DOE is also conducting oil shale research at its Lawrence Livermore Laboratory (LLL) and Sandia Laboratories.

In-situ research on the western U.S. oil shales was initiated by private industry. The Sinclair Oil and Gas Company conducted field studies in the rather shallow oil shales (up to 300 ft deep) on the southern rim (Haystack Mountain) of Colorado's Piceance Creek Basin, in 1953-54. A 31° API gravity, 2°C (35°F) pour point oil was produced. In 1965 Sinclair continued field experiments in the deep shales of the northern Piceance Creek Basin, but has never published any results from these later efforts. However, the results are believed to have been disappointing.

Between 1965 and 1967 Equity Oil conducted field experiments in a naturally-fractured shale zone some 305 meters (1,000 ft) deep in the center of the Piceance Creek Basin, using circulating hot methane gas. A minus 29°C (minus 20°F) pour point oil was produced, but methane loss was excessive. In 1968 Atlantic Richfield reactivated the venture. In 1970 a change was made to steam as the heat transfer medium, and well-spacings were reduced. The project was terminated in 1971.

Within the past 10 years, in-situ field experiments have also been conducted in the Piceance Basin by Mobil Oil (in shallow-depth shales), by Humble Oil (in lower zone shales), and beginning in 1970 by Shell Oil Company, using hot miscible fluids containing H_2S and/or other solubilizing agents. No results from any of these efforts have been published (as of December 1976).

Beginning in 1964 CER Geonuclear and a consortium of private companies proposed in-situ nuclear rubblization of shale and subsequent retorting at a Piceance Creek Basin, Colorado site (Project Bronco). A similar experiment was suggested for the Utah oil shales (Operation Utah). Public opposition to these proposed nuclear experiments, however, forced their abandonment in 1968.

In 1972 Occidental Oil Shale, Inc. (as Garrett Research and Development Co.) began investigation of its modified vertical in-situ process at a site near Debeque, Colorado, on the southern rim of the Piceance Creek Basin. The process involves underground mining of 20% of shale or barren rock to create void space, followed by chemical explosive rubblization and batch retorting. Underground room No. 4, a commercial-size retort some 37 meters (120 ft) square by 85 meters (280 ft) high, was ignited in mid-December 1975. A fifth retort of similar dimensions was prepared (see Occidental Process overview report).

Occidental was selected by ERDA (now DOE) for joint support of a demonstration in-situ plant under the Federal Non-Nuclear Energy Act of 1974, beginning in FY 1977. ERDA-shared support under this same Act was forth coming for (a) Geokinetics, Inc. which had begun field tests of its modified horizontal in-situ process in the Uinta Basin, some 15 miles south of the federal lease tracts Ua, Ub; and (b) Talley-FRAC Corporation of Mesa, Arizona.

In 1975 Western Oil Shale Corporation (WESTCO) and a ten-company consortium proposed a modified vertical in-situ project involving three underground retorts at a site in the Uinta Basin in shales near Bonanza, Utah.

A project planning phase was completed as of late 1976.

LERC/DOE IN-SITU FIELD RESEARCH PROGRAM

The potential application of nuclear explosions to in-situ energy resource recovery under the AEC Plowshare program was the primary motivation for increased federal government interest in in-situ oil shale retorting, beginning in the early 1960's. A 9 tonne (10 ton) batch shale retort using large pieces for simulated in-situ experimentation was put in operation at the Laramie Petroleum Research Center, Bureau of Mines (LPRC/USBM)† in 1965, and was followed by a 136 tonne (150 ton) retort in 1969. These batch retorts still continue to be used for evaluation of in-situ engineering parameters.

Initial Field Testing Program

In late 1965 LPRC/USBM began a series of field experiments concerned with in-situ fracturing and retorting of oil shale at a location midway between Rock Springs, Wyoming and Green River, Wyoming (Section 15, T 18 N, R 106 W). Some nine different sites had been used as of 1976 as shown in Figure 41. The oil shales are those of the Tipton formation, at depths as much as 46 meters (150 ft) below the surface.

The types of research conducted at the first eight sites is summarized in Table 11. As noted, these have included fracturing tests involving electrolinking, hydraulic, and explosive techniques, and several true in-situ retorting and steam injection experiments. Work at most of these 8 sites has now been abandoned, but work conducted at site 9 is more fully described below.

Table 11. Types of Research at LERC Rock Springs, Wyoming Sites*

	Fracturing Research				
Site	Electrolinking	Hydraulic	Explosive	In-Situ Experiment	Steam Injection Experiment
1	X	X	X	-	-
2	X	-	X	-	X
3	-	X	X	-	-
4	X	X	X	X	-
5	-	X	X	-	-
6	-	X	X	-	-
7	-	X	X	X	-
8	X	X	-	-	-
9	-	X	X	X	-

*Adapted from Burwell, E. L., et al, USBM Report of Investigations 7783 (1973)

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† LPRC/USBM became LERC/ERDA in January 1975, and later became LETC/DOE.

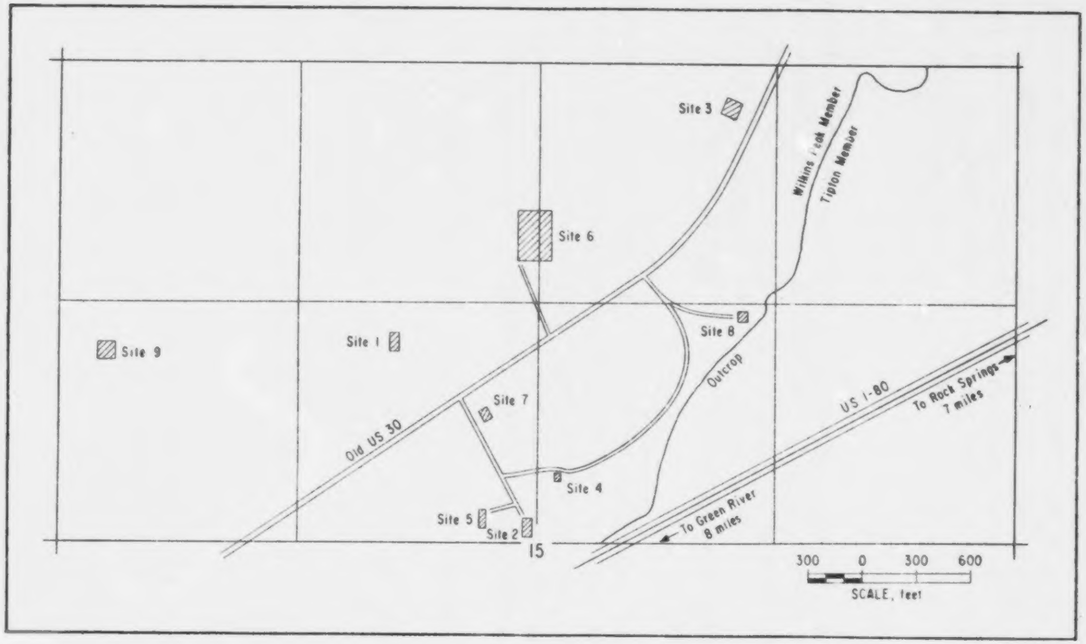
Site 3
Wilkins Peak Member
Tipton Member
Site 6
Site 9
Site 1
Site 8
Outcrop
Site 7
Old US 30
US I-80
To Rock Springs
7 miles
Site 4
Site 5
Site 2
15
To Green River
8 miles
300
0
300
600
SCALE, feet

Figure 41. LERC In-Situ Sites, Sect. 15, T 18 N, R 106 W, Rock Springs, Wyo.
(from Jackson, L. P., et al, Colorado School of Mines Quarterly 70, 105-134, October 1975)

Much of the work at the first 8 sites was done primarily to establish test conditions, but the results from sites 4 and 7 are worthy of further note.* At site 4 electrolinking and hydraulic fracturing were used to produce a bed of broken shale 6.1 meters (20 ft) thick and 7.6 meters (25 ft) square with less than 30 meters (100 ft) of overburden. A five spot well pattern was drilled. Following ignition some 400 barrels of oil were obtained over a retorting period of 42 days.

Site 7 was a 10-day test involving ignition of a 6.7 meter (22 ft) thick shale bed 21-27 meters (70-90 ft) below the surface. The shale was broken by pelletized-explosive well bore shooting and hydraulic fracturing. Some 400 gallons of oil were collected from the 5-spot well pattern during the 10 days of in-situ retorting before the experiment was discontinued.

From the results at sites 4 and 7, the Bureau concluded that a combustion zone can be established and propagated in an in-situ fractured oil shale body at shallow depths without substantial loss of permeability. However, yields of retorted oil were poor, in part due to readsorption into the formation. The oil itself had a lower pour point (-1°C or 30°F) and a higher volatility than shale oil from surface retorting.

1972-76 Fracturing and Oil Recovery Field Program

The current series of Laramie field experiments on fracturing and in-situ oil recovery have been underway since 1972 at the Rock Springs, Wyoming field sites. In one experiment on a 0.4 hectare (one acre) site, fracturing was attempted by using about 182 kg (400 lbs) of pelletized TNT in each of 53 well bores. Simultaneous detonations were carried out in two to four wells at a time. A system of horizontal fractures was formed at a depth of 38 meters (125 ft).

The bed was ignited and combustion was continued for several months. Oxygen utilization was high and CO_2 production substantial, but essentially no oil was produced due to insufficient exposed fracture surface area.

A new test site (No. 9) was prepared in order to further examine fracturing techniques, in-situ oil recovery, and fluid migration before, during, and after combustion and retorting. A 9-spot drill pattern was used involving two concentric rings of 4 wells each at 11-15 meters (35-50 ft) from a central injection well. Some 10 additional observation wells were drilled for hydrologic monitoring. The oil shale to be fractured and retorted was a 12 meter (40 ft) thick bed in the Tipton formation at a depth of approximately 41 meters (135 ft). The well pattern is shown in Figure 42.

The bed was prepared by three hydraulic fracturing treatments followed by two treatments with liquid explosives. Three major horizontal fractures were created of sufficient permeability to permit water flow between all walls. An attempt to enlarge the lower horizontal fracture, using hot water extraction and air, proved unsuccessful.

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*Burwell. E. L., et al. In-Situ Retorting of Oil Shale, Results of Two Field Experiments, USBM Report of Investigations #7783 (1973).

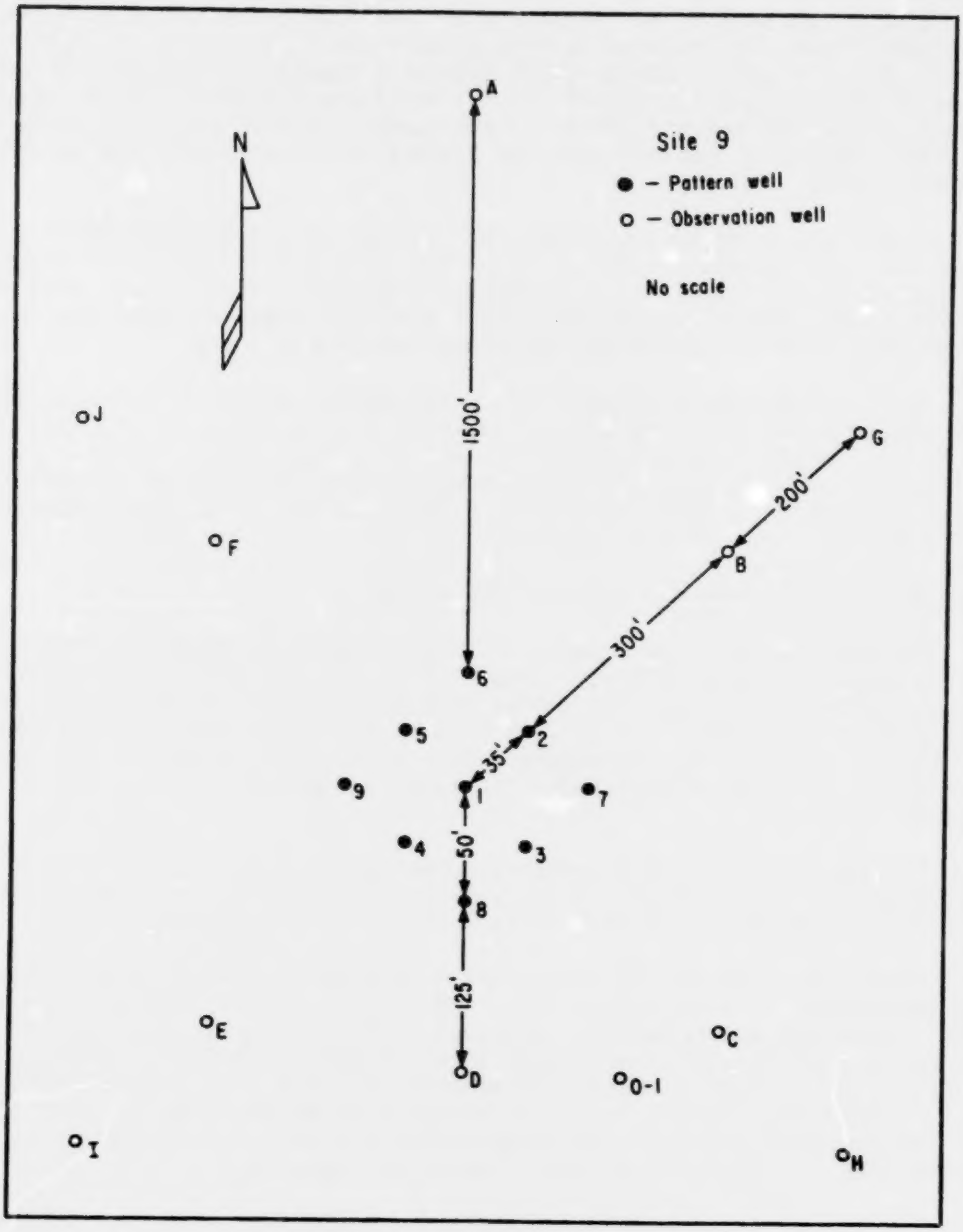
A
N
Site 9
● – Pattern well
○ – Observation well
No scale
1500'
J
G
200'
F
B
300'
6
5
2
35'
9
1
7
4
50'
3
8
125'
E
C
D
O-1
I
H

Figure 42. Well Pattern for In-Situ Site 9
No. 1 - Injection Well
Nos. 2-8 - Production Wells
Letters - Observation Well
(from Jackson, L. P., et al, Colorado School of Mines Quarterly 70, 105-134, October 1975)

Ignition was started on April 5, 1976, and propane injection continued until April 21, after which air alone was injected at rates of up to 5.7 - 6.4 cu meters/min (200-225 CFM) and pressures of 3.5-8.0 kg/sq cm gauge (50-115 psig). Down-hole temperatures of 870°C to 1370°C (1600 to 2500°F) in the production wells and monitor wells indicated that combustion was successful, and that the burn and retorting zones were proceeding toward the production wells.

Gas recovery was 4.65 x 10^6 cubic meters (165 x 10^6 cu ft) during the first 35 days. The gas had a net heating value of 267-356 kcal/cu meter (30-40 Btu/cu ft). About one-half barrel of shale oil per day was being produced, half of which was naphtha and light gas oil and the remainder light distillate, heavy gas oil, and residuum. In the first 35 days of operation some 2650 ltrs.(700 gal) of oil with a gravity of 26° API and a pour point of 4°C (40°F) were produced. Yields were poor. As of September 1976 the burn was still proceeding although retorting conditions in the bed had not yet been optimized.

Exploratory Drilling Program

A field program of exploratory drilling of a series of coreholes, boreholes, and black trona brine wells has been initiated in the Northern Green River Basin of Wyoming (See Figure 43). One objective is to evaluate the extent, richness, and geology of the Tipton, Wilkins Peak, and Laney Shale members of the Green River Formation in the Basin. Another goal is to locate a suitable shallow deposit of shale in the Laney member on White Mountain for a subsequent modified horizontal in-situ field test.

Environmental Aspects of In-Situ Shale Processing

Laramie has initiated a number of research programs to investigate the environmental changes associated with in-situ oil shale processing. Among these are the following.

Fluid Migration Field Studies. In 1974 a long-term program was begun to examine underground fluids migration prior, during, and after in-situ processing of shale. As part of this study, water and brine samples are taken at monthly intervals from the wells and coreholes in the above-mentioned exploratory drilling program in the Northern Green River Basin. These, together with the White Mountain well(s), provide data prior to in-situ processing.

The 10 hydrologic observation wells which are part of the current in-situ test at Rock Springs Site 9 furnish data during actual in-situ shale oil recovery. They also permit further study of the underground fluids after in-situ processing is completed in order to detect any possible in-place pollution effects.

Because of the large number of inorganic and organic constituents which could be measured, it is necessary in all of these fluid migration studies to limit the number of parameters to be monitored to those which are considered to be (a) particularly significant, and (b) adaptable to routine analytical techniques. In this connection, efforts at LETC/University of Wyoming to separate and utilize the organic and inorganic components from the aforementioned

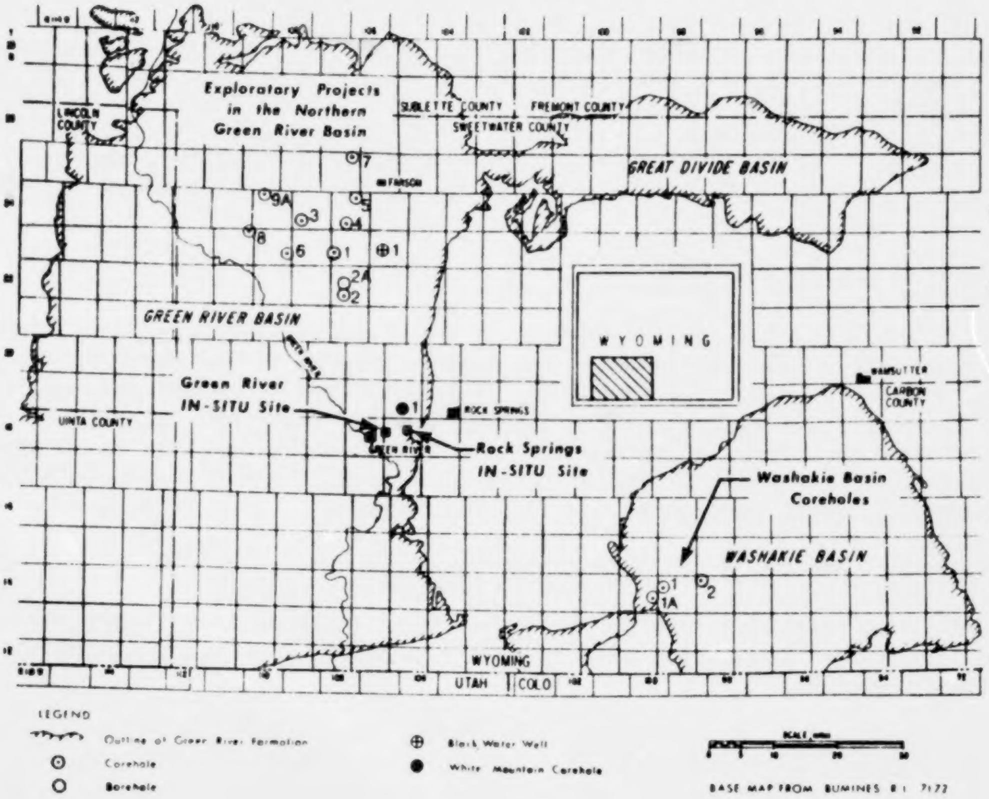
Exploratory Projects in the Northern Green River Basin
LINCOLN COUNTY
SUBLETTE COUNTY
FREMONT COUNTY
SWEETWATER COUNTY
GREAT DIVIDE BASIN
FARSON
9A
3
8
6
4
5
7
1
1
2A
2
GREEN RIVER BASIN
WYOMING
Green River IN-SITU Site
1
ROCK SPRINGS
GREEN RIVER
Rock Springs IN-SITU Site
UINTA COUNTY
WAMSUTTER
CARBON COUNTY
Washakie Basin Coreholes
WASHAKIE BASIN
1
1A
2
WYOMING
UTAH
COLO
LEGEND
Outline of Green River Formation
Corehole
Borehole
Black Water Well
White Mountain Corehole
SCALE, miles
0
5
10
20
30
BASE MAP FROM BUMINES R.I. 7172

Figure 43. Location of LERC Field Studies, Sweetwater County, Wyo. (base map from USBM Rept. Invest. 7172 (1968); location map from Cameron Engineers, Synthetic Fuels Quarterly Report 12, No. 1, 2-10 March 1975)

black trona water wells in the Northern Green River Basin are providing a valuable analytical experience since this water may be thought of as partially analogous to waste-fluids from in-situ processing.

Supporting Environmental In-Situ Research. A planning effort was conducted to determine a comprehensive approach to the management of oil shale retort water. The potential toxic constituents in retort water were identified and their biological degradation examined. Trace elements analyses were also conducted.

ERDA In-Situ Demonstration Projects

In February 1976 ERDA invited proposals for "research, development, and demonstration of alternative methods for in-situ recovery of shale oil" under a cost-share program. The Program Opportunity Notice (PON) specified five possible types of in-situ processing, viz, true in-situ, vertical modified in-situ with mining, horizontal modified in-situ with mining, horizontal modified in-situ with fracturing, modified in-situ with solution mining.

Nine industrial firms responded with projects, from which four were selected for cost-share funding under the Federal Non-nuclear Energy Research and Demonstration Act of 1974. The four firms were: Geokinetics, Inc. (horizontal modified in-situ); Occidental Oil Shale, Inc. (vertical modified in-situ); Equity Oil Co. (true in-situ with fracturing); and Talley-Frac Corporation (explosive fracturing). DOE's Laramie Energy Technology Center assists in technically monitoring these in-situ projects as they proceed, and in providing associated laboratory support.

LETC/DOE SUPPORTING LABORATORY RESEARCH

The technical staff at LETC/DOE is continuously engaged in laboratory research programs to provide fundamental engineering and scientific data in support of the in-situ field programs, as described below.

Ten Ton and One Hundred Fifty Ton Batch Retorts

Mention has already been made of the previous use of the 10-ton and 150-ton batch retorts for examining the engineering variables associated with in-situ processing. These large-scale batch studies are continuing. Further tests are in progress to examine the effects of shale size and richness on oil recovery yields.

The 150-ton retort is being employed to further elucidate earlier observed temperature anomalies in large oil shale blocks. Large granite blocks are being simultaneously loaded with the shale. A study is also being conducted in the large batch retort of the mechanism of retorting in atmospheres of varying oxygen content.

Gasification of Oil Shale

The gasification of shale has been investigated in an adiabatically-shielded high pressure bench-scale retort since 1973. Over 120 runs had been completed by 1976, in the presence of varying amounts of CO_2, O_2, N_2 and steam and pressures up to 39 kg/sq cm gauge (550 psig), using 46 to 220 liters/tonne (11 to 53 gal/ton) oil shale. The resulting off-gas has varied in heating value from 445 to 11,570 kcal/cu meter (50 to 1300 Btu/cu ft).

The horizontal retorting and gasification runs have now been completed, and vertical retorting and gasification studies have been initiated. Work is also being completed on a large retort or about 0.45 tonne (0.5 ton) capacity in which better heat and material balances can be obtained during gasification than are possible with the present bench-scale unit.

Controlled State Retorting

A 7.6 cm (3 in) diameter batch, vertical, controlled state retort (CSR), electrically heated by 24 individually-programmed heating elements, is being used to examine various retorting variables. The conditions are similar to those encountered in the underground rubblized chimney of a modified vertical in-situ retort with its down-flow of hot gases and lower, cool, unreacted shale zone.

The data to date indicates a noticeable decrease in yield of lower boiling shale oil fractions at higher oxygen contents in the retorting atmosphere. The research is being continued and includes a program of planned kinetic studies.

Pressure Retorting

A 129 liters/tonne (31 gal/ton) shale has been studied in a vertical batch retorting process in which pressures from 0 to 105 kg/sq cm gauge (0 to 1500 psig) could be attained at varying heating rates and retort gas velocities. The retorting temperature was approximately 510°C (950°F). Increasing pressure resulted in a decrease in Fischer assay oil yield from 90% (at atmospheric) to 70% (at 1,500 psig), increased gas production and carbon deposition on the retorted shale, and a lower boiling shale oil. When a hydrogen sweep gas was used, oil yields increased at higher pressures to greater than 100% of Fischer assay.

Retorting Using Carbon Monoxide and Water

The pyrolysis of oil shale is being examined in the presence of CO and H_2O in a bench-scale reactor at 300°C-450°C (570°F to 840°F), CO charge pressures of 70 kg/sq cm gauge (1,000 psig), and heating times of 0.25 to 1 hour. Higher kerogen conversions to soluble products were obtained at lower temperatures with CO/H_2O than by dry thermal pyrolysis. The water-soluble minerals produced resulted in retorting residues less susceptible to subsequent leaching.

Miscellaneous In-Situ Related Laboratory Programs

Improved analytical techniques applicable to the current laboratory and field in-situ programs continue to be developed. The conversion of in-situ shale oils to useful gaseous and liquid products and their adaption to latest refining technology is being examined. A study has been initiated on the storage stability of hydrogenated shale fuels. Research is proceeding on the oxidative removal of nitrogen compounds from various shale oil fractions, and on solvent extraction of shale oils to produce cuts more amenable to hydrogenation.

SUGGESTED RECENT LITERATURE REFERENCES

1. Ramsey, J. W., "Implementation of the Energy Reserach and Development Administration Accelerated Oil Shale In-Situ Research Program," preprint 81st National Meeting, AIChE, Kansas City, Mo., April 11-14, 1976.

2. Carpenter, H. C., "Preliminary Results of Five Oil Shale Conversion Experiments," preprint, 9th Oil Shale Symposium, Colorado School of Mines, Golden Colo., April 29-30, 1976.

3. Burwell, E. L., et al, "In-Situ Retorting of Oil Shale - Results of Two Field Experiments," USBM Report of Investigations 7783 (1973).

4. Harak, A. E., et al, "Oil Shale Retorting in a 150-Ton Batch-Type Pilot Plant," USBM Report of Investigations 7997 (1974).

5. Miller, J. S., "Fracturing Oil Shale with Explosives for In-Situ Oil Recovery," USBM Report of Investigations 7874 (1974).

6. "Accelerated Oil Shale In-Situ Research - A National Program," Interagency Oil Shale Planning Panel, Washington, D.C., March 1975.